

TOM GREEN COUNTY.

San Angelo (post-office), Joseph Tweedy (September, 1891):

Water supply: Dove Creek, appropriation about 20 cubic feet per second.

Works: Twelve miles of ditches, 6 feet on bottom, from 18 inches to 8 feet in depth; no reservoirs; one dam; one headgate: no other works.

Area under ditch and under cultivation 1,400 acres.

Cost per mile of ditches, \$400; cost of reservoirs and other works, \$1,000.

Average cost per acre for irrigation works, ditches, etc., \$4 to \$5.

Average cost per acre for annual maintenance and repairs, \$1 to \$1.25.

Average cost per acre for preparing land for cultivation under irrigation: Grubbing (when necessary), \$4; breaking \$3.

Land is rented for one-third of the crop, water furnished.

Water costs the owner only annual maintenance and repairs.

Products: Wheat, oats, corn, cotton, alfalfa, millet, Johnson grass, fruit, sweet potatoes, and other vegetables.

Estimated value of product per acre, \$20 to \$25.

PAPERS

ACCOMPANYING

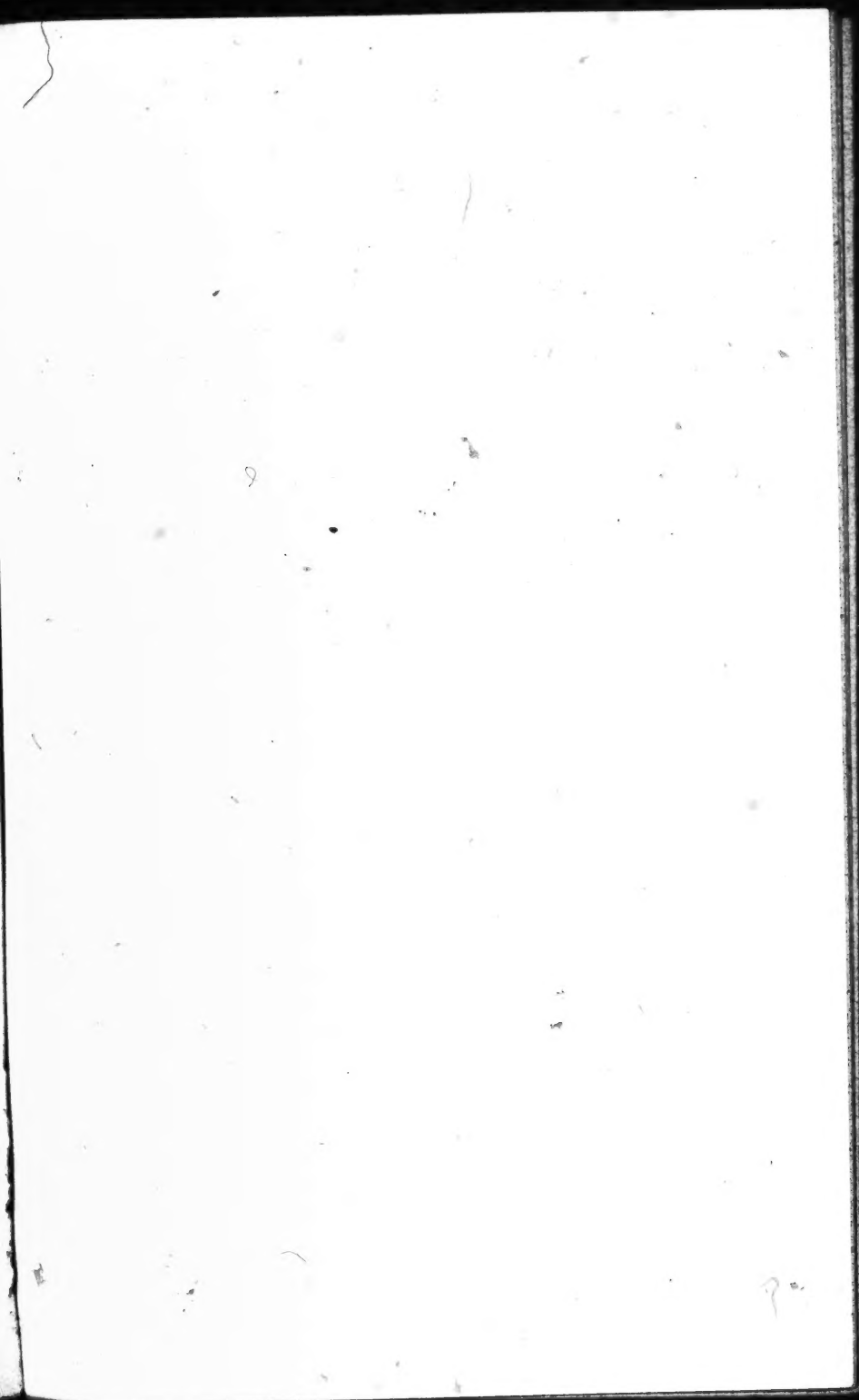
THE REPORT OF THE OFFICE OF IRRIGATION INQUIRY,
DEPARTMENT OF AGRICULTURE.

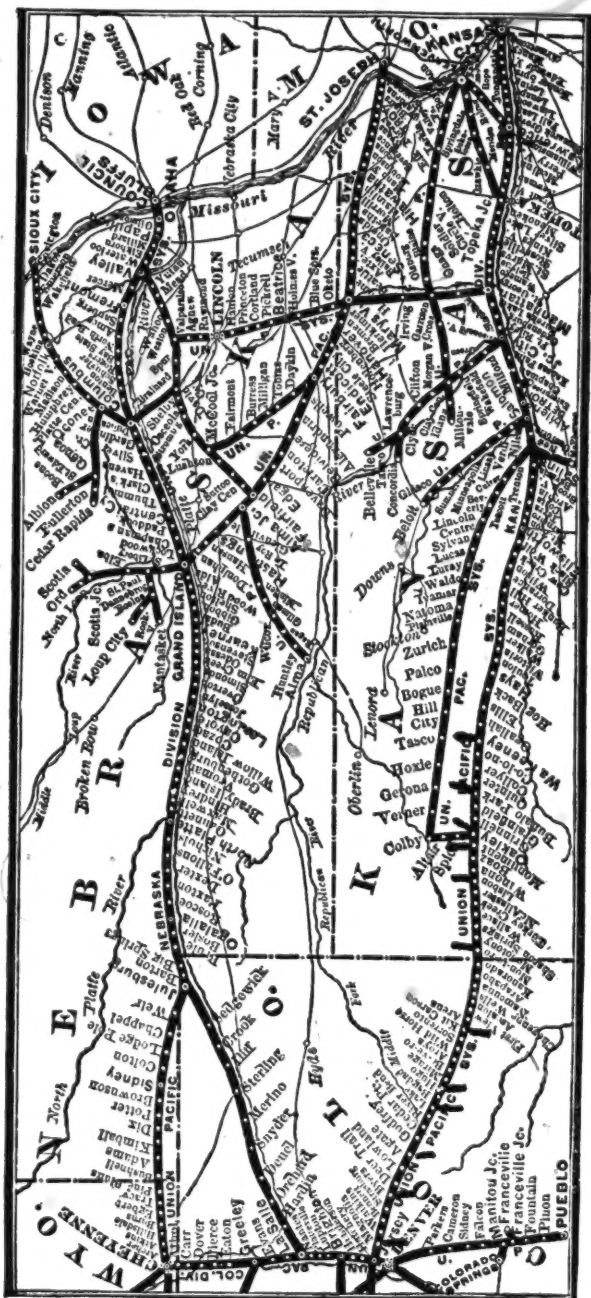
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MAP OF KANSAS DIVISION OF UNION PACIFIC RAILWAY.

The points marked "1" indicate the wells stations, whereat observations of underflow are being taken

PRELIMINARY REPORT ON THE POSSIBILITIES OF THE RECLAMATION OF THE ARID REGIONS OF KANSAS AND COLORADO BY UTILIZING THE UNDERLYING WATERS.

BY HOWARD MILLER, PH. D.

OCTOBER 9, 1891.

SIR: I have the honor to transmit my report on the possibilities of irrigation on the arid plateau of Kansas and Colorado.

HOWARD MILLER.

Hon. EDWIN WILLITS,
Assistant Secretary of Agriculture, Washington, D. C.

DEVELOPMENT OF THE ARID PLATEAU OF KANSAS AND COLORADO.

The last generation of schoolboys learned from their geographies that the vast and little understood trans-Missouri region was known as the Great American Desert. It was asserted, and almost universally believed, that the Plains' country included in this alleged desert would never be fit for the occupancy of man.

But as the years passed adventurous pioneers, taking the overland route to the Golden Gate, noted the streams and their fringe of forest growth and built themselves homes in the valleys.

Thus it was that the eastern portion of the so-called arid region was invaded and made amenable to the demands of civilization. From these beginnings the population spread westward, thinning and separating as it neared the Rockies.

From the river to the mountains the soil was found to be perfect, the climate all that could be desired, and the general conditions, with but one exception, most favorable.

The factor that has rendered ordinary agriculture more and more uncertain as settlement progressed westward is the lack of rain at the time of its need by the growing crops.

The elevation above the sea level from Kansas City to Denver is steadily progressive; at the former place it is 681 feet, and at Denver 5,170 feet.

To the scientist this single condition bars the continuous success of the same methods of agriculture along the line of country under consideration. There are no natural boundaries to this huge incline, but the State of Kansas is usually spoken of as being divided into three sections—eastern, middle, and western, though this classification is purely arbitrary. In the eastern portion diversified agriculture is as successfully prosecuted as in any other State. In middle or central

Kansas the seasons, whether wet or dry, play an important part in the farmer's returns, while in western Kansas it may be regarded as settled that ordinary mixed husbandry can not be relied upon with any certainty of success.

From the eastern border of Colorado to Denver the conditions of the western third of Kansas are continued.

To fully comprehend the immensity of the sections so briefly described a personal inspection is necessary. It must not be imagined that the ever-increasing altitude and the word Plains' imply a vast and perfectly level stretch of country with an imperceptible rise in grade. There are enormous reaches, aptly described by the current phrase "as level as a floor," and then there are valleys, miles between their crests, gently rising and joining hands with the blue sky.

There may be selected in this empire hundreds of square miles having any desired exposure and each so inclined that an antelope would be visible on any part of it.

On the plateau of western Kansas and eastern Colorado there are no native trees—buffalo grass covers the earth—it is green in the spring time and cures into a natural food for stock. It is a matter of surprise to the stranger that there should be thousands of cattle knowing no other food from calfhood to the shambles.

This land will produce anything that will grow in its latitude in the utmost profusion, if it only has water during the growing season. With its magic touch there may be opened up a literal garden of the gods that can feed the earth. There is but one key which will unlock this vast storehouse of the earth and make its products available, and this is best symbolized by the actual fact—a ditch with flowing water.

When we speak of irrigation to the average Eastern man we put up a scarecrow, but to the Plains' man the talk is of gold.

Irrigation is as old as man's earliest efforts at agriculture. Its application is as varied as the country and locality in which it is practiced, and it may be broadly stated as the commonest form where man turns a stream into a ditch and diverts it from the main source of supply to the fields he wants to water.

If there is no available stream he may drill an artesian well and turn its waters into his fields. Between these two forms there are countless methods not germane to the subject here under consideration.

On the high plateau of Kansas and Colorado there are no available streams, nor is there hydrostatic pressure to force water above ground if artesian wells were sunk. The theory that planting forests will produce rain is inapplicable, as trees will not grow without water, and if there is water to insure their growth the trees are not directly needed. In passing, it must not be inferred that rain does not fall in the arid and sub-arid regions under consideration. It does, but the precipitation and the time of its need by growing crops are hardly ever synchronous; that is, the rain does not come when man needs it.

It is a common saying that if the country was plowed and cultivated rainfall would be produced. This is thoroughly fallacious. Climate makes vegetation and vegetation is a result, not a cause.

Plowing the soil makes it retentive of the moisture that does fall, and only thus far does the cultivation of the earth assist nature. I do not believe that this entire arid section could be cultivated, which is an utter impossibility, but assuming that it could be done, I am of the opinion that a rainfall appreciably greater would not result.

The formation of reservoirs on elevated portions of the farms has been urged, and this plan will doubtless constitute a feature of irrigation in many places.

If, then, there are no available streams on the plateau or in many other portions of the Great Plains, and if there is not a sufficient rainfall, must this magnificent country necessarily be abandoned to the herder? The writer feels that this is not a sequence of the conditions as stated, and he is of that opinion for the following reasons:

There is no fact better established than that this high altitude region is thoroughly well supplied with subterranean waters. This is shown conclusively by the fact that the railroad company to secure the water necessary for its engines has dug wells at intervals along the line. These wells are of varying depth and diameter, and are located right along the rails. They were dug for railway purposes with no immediate or remote contingency of their use for common agricultural purposes in view. Where the distance between wells allowed the company utilized a site in close proximity to a stream, or rather the bed of a stream, and in all such cases the wells are shallow. The reason is apparent. The water running down the bed of the stream percolated through and saturated the adjacent strata and the waters readily fill the well. But there are other wells on high ground, far removed from any stream or dry bed of a stream, and in all of these water is had in abundance. Of course these wells are deeper than those nearer streams. It is manifestly clear that the entire arid region is underlaid with water. This water varies in quantity and quality, but only in rare instances is it so charged with mineral matter as to be unfit for use.

Some of these wells are fitted with wind engines, and others are pumped by steam, still others have a combination of the two, steam supplementing the wheel in calm days. The water is pumped from the well to the water tank, familiar to everybody who has ever taken a railroad journey of any length.

Nothing is commoner in the vicinity of these wells than the assertion that the water supply is inexhaustible, and nothing is more incorrect, as will be shown further on.

It is well to note the fact that two theories obtain in reference to the existence of this water. One is, that it is sheet water that has percolated through the porous strata, fed from the rains and melting snows, in loco, and passing through the earth downward and laterally from the stream beds, which are invariably of sand or gravel of greater or less coarseness.

The other is that the entire plains country is underlaid with a deposition of gravel and sand, through which the waters of the streams and slopes of the Rocky Mountains slowly work their way eastward.

The writer does not know which theory is correct. It is certain, however, that water underlies the arid region. If it should be established that it exists in sufficient quantities to be made available on a large scale, the question is then one of simply raising the water to the surface and properly distributing it—problems easy of solution. If this underlying water is simply slow seepage, readily exhausted from the well, then neither ditches nor reservoirs are available, and the land inures to the stockman. If, however, this water varies in quantity, if there is a rise or fall, depending on freshet or season, and a practically inexhaustible supply by reason of its being caught on the rise and stored against the day of its use, then is the great American Desert to be renamed and known as the Great American Garden.

Can this fact be determined? At first blush it would seem an impossibility, yet the writer not only believes it possible, but is at the present engaged in the settlement of the question. To do this satisfactorily the following tests and experiments have been begun:

Along the line of the Union Pacific Railway there is a number of dug wells. The line passes through the very heart of the area under discussion, and every well taps the subterranean supply of water, the very lifeblood of this section, that must be made to flow through the arteries of an irrigation system to make this country available as a field for agricultural operations. These wells vary in size, depth, and water supply. They were constructed with a view to securing water for the engines, and when this had been attained the work was finished. A brief description of one of these wells will get before the general reader an idea of their usual make-up. At Weskan, in western Kansas, within a few miles of the eastern border of Colorado, on high ground, removed from any stream, is one. It is 132 feet deep, walled with huge stones, is 12 feet in diameter in the clear, and has 11 feet of water. Just above the surface of the water, at the bottom of the well, on a stout platform laid on timbers built into the wall, is a steam pump operated by an engine on the ground at the top. The water is pumped into the tank as needed. The well reaches the sand and gravel in which the water is found.

In this well the following apparatus is set up: A round box float of galvanized iron, resembling a small cheese box, water tight, and loaded with sand, rests on the surface of the water in the well. Attached to this float is a light copper chain, which is passed up to the ground floor of the well and over a 4-inch pulley. At the other end of the chain is a leaden counterpoise balancing the float. It will be apparent that when the water in the well rises, the float rises, and the counterpoising weight sinks, keeping the chain taut. When the water falls the float drags down the weight. It only remains to attach an index to the chain at the surface, moving up and down on a fixed scale graduated into feet and inches, and every rise and fall of the water is registered. The apparatus is simple, efficient, and wonderfully exact.

The well attendant records on a prepared blank the depth of the water at sunrise and sunset before and after pumping and the amount pumped out. In connection with the well float is a thermometer and rain gauge near the tank, and thus it will be seen that the relation between the precipitation and the water in the well is readily shown.

After the Weskan well experiment had progressed favorably it was determined that the tests should be extended, and a selection of twelve wells, covering a distance of several hundred miles, was made and each one similarly fitted with floats, rain gauges, etc., and the tabulation of results begun.

It will be perceived that in any event enormously valuable results accrue from these records. If it should be demonstrated that rain or freshet has no effect on the water supply, or that the seasons bring a tide, a slow, huge wave, lifting the water in each well from the west to the east, much will be settled thereby. If, on the other hand, the seasons show no change, and the heaviest rains produce no results in these subterranean waters, the inferences are equally definite.

The experiments have not, at this writing, proceeded far enough to show results upon which to assert an established fact. The freaks of the registration at Weskan require verification and corroboration by the records of the other wells along the line. The results, will in the end, largely settle this underflow talk, of which every man has a theory, and no man *knows*. In the end, the reports are to be published, and there will be no more reasonable doubt about the result than attaches to the findings of a gauger who measures the contents of a series of barrels in a cellar, every day of the year. Of course no such result

may be attained without Congress authorizing, through law, the further prosecution of such work.

It is a remarkable fact that in the vicinity of these wells the residents are apt to consider them inexhaustible. This statement has been made over and over again at Weskan. Yet when the well had been fitted with the apparatus, and the pump, throwing a three-inch stream, was started, the index almost immediately recorded a fall in the water and continued to steadily fall while the pumping lasted, and a minute thereafter the water began to fill up the well. The incident is mentioned to show that the talk, the opinions of men, honest in every respect, and the facts are not always in harmony. With this principle in view the writer, although thoroughly cognizant of the results thus far accrued, does not hazard an opinion as yet. When the results of the twelve well tests are all in, and set side by side, for a series of months, the conclusion will then be a solid foundation, and a fact, not an opinion.

The results, however, amply justify the continuance of the experiments, as affecting an enormous stretch of country where there is neither running water nor storage possible from precipitation. If at the conclusion of the experiment, it is deemed prudent to further continue the test, I recommend that the most promising well be deepened till a practically inexhaustible supply is reached, and this, if found, reduces the whole question of the occupancy of this arid region to a powerful pump and a properly laid out ditch.

There are many places where this is done in the miniature, with a wind pump, but it is not available to the pioneer, who is never a capitalist. No individual can undertake the development of this region in the manner and on the scale here suggested. This question should be brought to a certainty by means of such preliminary development as will render private action in the premises reasonably sure of success.

The results, if successful, would be bewildering. Where the bare, brown plains stretch away in the distance, the home of the prairie dog and the antelope, no reach of imagination is required to see a mental photograph of the tree-lined village, the garden with enormous vegetables, the town about the central water supply and the green and growing crops as far as the eye can reach. It is a beautiful picture, every color of which inheres in the water underlying the scene.

The points that follow may be regarded as established facts:

(1) Every Union Pacific Railway well between Kansas City and Denver can be pumped dry.

(2) The elevation does not have much to do with access to water, showing that the water-bearing strata are not of uniform deposition.

(3) The water is generally good and is used by the residents for many miles around the wells in the more unsettled portions.

(4) Where the water is bad inorganic matter is in solution, and this varies in quantity and quality.

(5) A fairly uniform depth may be expected for wells on the same general plateau.

(6) Failure to find water is rare.

(7) No engineering difficulties present themselves, that is, none which are insurmountable.

(8) The difference in elevation between the eastern and western well test is 2,927 feet.

(9) The average fall from west to east is about 9.54 feet per mile for the distance covered.

(10) In places penetration of the fresh-water strata results in securing salt water.

The writer wishes to thank the honorable Secretary of Agriculture, and Mr. B. A. McAllaster, of the Union Pacific Railway, for their aid and sympathy in the investigation. He further thanks the well attendants, and others rendering service at the several points of test.

The tables in this report show the altitudes and locations of the well tests. Publication of the entire results later on, when their extent, accuracy, and completion justify it, will, it is hoped, be authorized by law.

METHODS OF APPLYING WATER TO LAND, AS PRACTICED IN THE CENTRAL PORTIONS OF CALIFORNIA.

BY C. E. GRUNSKY.

Civil Engineer, San Francisco, Cal.

Irrigation is still a new art in California, and the methods of applying water to land which have found favor in different parts of the State are the outgrowth of attempts on the part of irrigators to adapt methods in use in other localities and countries to new conditions as here found. These attempts have met with more or less success, and have resulted in the adoption of a variety of methods of irrigation, each of which is more or less perfectly adapted to the peculiarities of climate, soil, and physical features of the region where practiced. When irrigation is accomplished with water from ditches the methods of irrigation may be classified as follows:*

Irrigation by flooding.

Irrigation from furrows.

Irrigation by causing a rise of the ground water.

Irrigation from subsurface conduits.

Flooding may be accomplished by turning water out of small ditches constructed on the highest ground and making it flow in thin sheets over the surface (not specially prepared) to be irrigated. This is locally called "wild flooding." Or it may be accomplished by constructing embankments of such height that the water which they restrain will cover the land. This is irrigation by flooding in checks. (A check is a compartment or basin inclosed by check levees.)

The embankments may be adapted to the configuration of the ground, each of the main embankments being placed on a contour line. The method of irrigation is then called "flooding in contour checks." If the embankments are constructed along the sides of rectangles the method of irrigation is then called "flooding in rectangular checks." The surface of the ground in a check can be made perfectly level. Irrigation in such checks is called "irrigation in level checks."

"Furrow irrigation," like flooding, is intended to supply water only to that part of the soil into which penetrate the roots of the plants, trees, vines, etc., to be irrigated. It is sometimes practiced for grain, more frequently for plants, trees, vines, etc., which are set out in rows. "Furrow irrigation with drainage" provides for the collection of all sur-

*No attempt is here made to describe methods of irrigation as practiced elsewhere, but it is hoped that California's experience may prove serviceable to other sections and irrigators. This data is brought down to August, 1891.

plus water flowing through each furrow and its subsequent utilization. "In furrow irrigation" no surplus water is permitted to enter any furrow.

"Irrigation by causing a rise of the ground water" can be practiced only under certain favorable conditions. It involves the rapid sinking of water from canals and ditches into the subsoils and imperfect drainage of the latter.

"Irrigation from sub-surface conduits" or "sub-irrigation," as it is generally termed, supplies water to the surface soils only through pipes or other conduits from which water escapes and permeates the soil.

It is well to bear in mind that it is just as important to conserve the moisture already in the soil as it is to add moisture. This fact has been taught by experience to the irrigators in San Joaquin Valley, and it has become a universal custom to cultivate the irrigated tract as soon after the application of water as possible. The surface soil is broken up and pulverized. The capillary forces of the soil are reduced to a minimum and the weeds kept down. The furrows in use to distribute water are plowed in, and if the irrigation is to be repeated the same season new furrows are drawn.

WILD FLOODING.

[See Plate No. 1.]

The practice of wild flooding can best be explained by reference to the diagrams illustrating this method of irrigation. In the plan, Fig. 1, the curved broken lines represent contours and indicate a slope of the surface of the ground in the direction from E to F. A A is a supply ditch, whose water is diverted as required, at C C, into irrigating ditches.

The irrigating ditches are sometimes permanent, sometimes temporary. Out from the irrigating ditches to the right and left, at the points D, are small embankments, with nearly horizontal crests. Material for their construction is taken from their upper sides, thereby forming a depression which serves the purpose of a watering ditch. These embankments are usually permanent, and are so flat that they do not interfere with ordinary farming operations. Irrigation is commenced by turning water from the supply ditch into the irrigation ditch at C. It is checked at D by means of a temporary dam of earth, or by means of a small gate, and flows to the right and left. As soon as water attains the height of the embankment, out from D, it commences to flow over them and to flood in a thin sheet the land intervening between the first embankment and the next one below. If too much or too little crosses the embankment at any point the defect is remedied by attendants, whose presence is constantly required during the process of irrigation. At the second point, D, the operation is repeated, and so on until the surplus water reaches an inlet into a drain ditch, which may at the same time be an irrigating ditch for other lands. The preparation of ground for this method of irrigation is very inexpensive, but the cost of applying water, owing to the constant attendance required, is great. One man can irrigate from 1 to 2 acres per day by wild flooding. This method of irrigation is sometimes called "mustang irrigation."

Fig. 2 is a section from E to F. Figs. 5, 6, and 7 illustrate an improved arrangement of a 4-foot gate for a small supply ditch.

Wild Flooding

Plate 1.

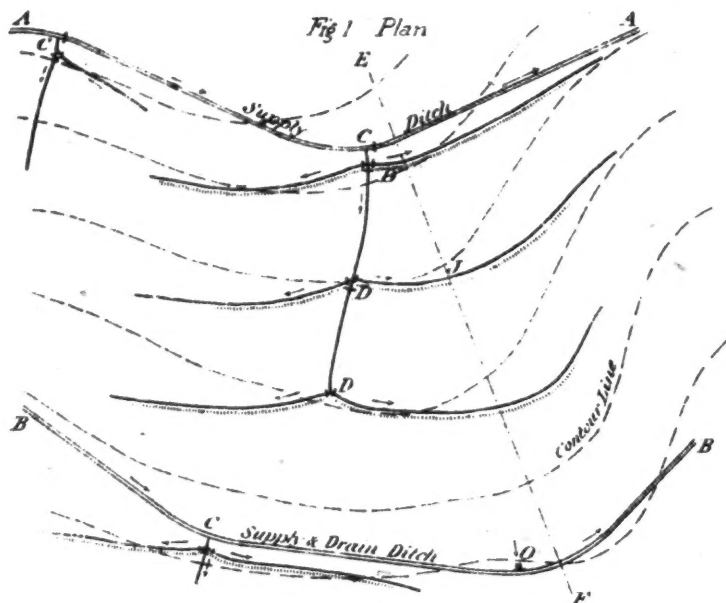
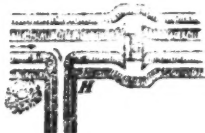


Fig 2. Section EF.



Fig 3 Detail at C.



Check Gate in Supply Ditch.

Fig 5. Plan.

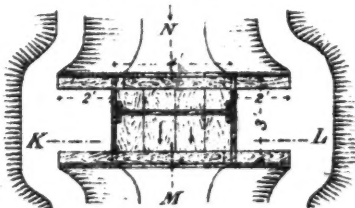


Fig 4. Ditch at J.



Fig 7. Section MN.

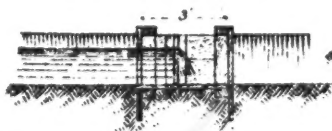


Fig 6 Section KL.



Flooding in Contour Checks.

Fig. 1 Plan.

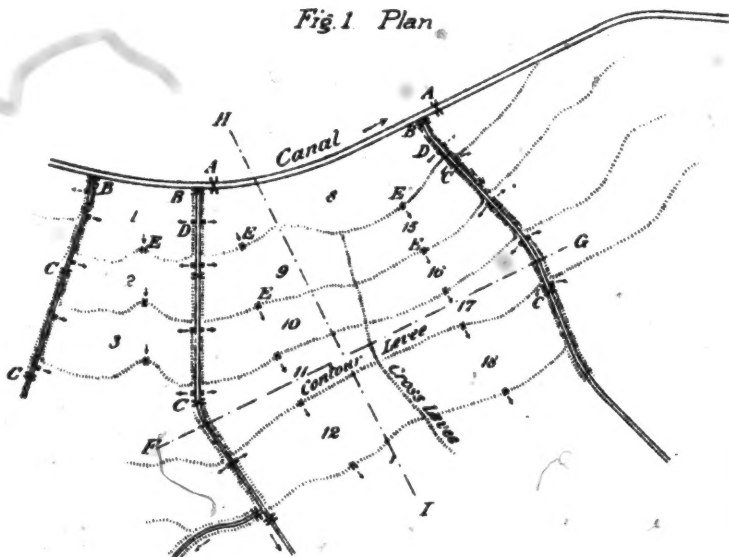


Fig. 2. Section FG (enlarged).



Fig. 3. Section HI (distorted).



Check-Levee Profiles

Fig. 4

Fig. 5



Fig. 6



FLOODING IN CONTOUR CHECKS.

[See Plate No. 2.]

When land is to be flooded by irrigating in contour checks, water is brought to the highest points of the tract to be irrigated by means of a supply canal or ditch, from which branches may lead off about in the direction of the greatest slope of the ground surface if this be not excessive. Distance between these irrigating ditches in practice is very variable, sometimes as great as one-half mile, but such distance is permissible only when very large volumes of water are available for flooding.

The farther apart that these ditches are placed the greater should be their capacity. The land between these irrigating ditches is divided into compartments by levees constructed from ditch to ditch on contour lines. These should not be made more than 12 to 18 inches high. The total fall of the ground from one to the next lower may be 6 inches to 1 foot. Where the ground is sufficiently flat to permit of less fall between the levees it is still better to adopt a fall of less than 6 inches. Where the ground is so steep that levees more than 1 foot apart in vertical elevation would be required in order to obtain the necessary space between them for the levee construction, some other system of irrigation should be adopted.

When the compartments between ditches and successive contour levees are too large they are frequently subdivided by a cross levee midway between the two ditches. This method of irrigation is illustrated by plans and diagrams on Plate No. 2.

At the points A A of the main canal are check weirs (drops or gates). At B B B are the head gates of the irrigating ditches. At C C C are check weirs in the irrigating ditches. At D D D are gates in the sides of the irrigating ditches which serve to admit water into the compartments or checks to be flooded. At E E E are gates in the levees between checks through which surplus water of any check may be allowed to flow into the one next below it.

To irrigate the check No. 1 water is admitted into the irrigating ditches upon each side of it, and from these through D D into the check. As great a volume of water as possible is forced into this check until the contour levee backs it upon the main canal levee. As soon as this occurs the irrigation of the land in this check is complete, and the gate at E between 1 and 2 is opened at the same time the gate from both irrigating ditches into check No. 2 are opened, and the operation is repeated for each check in turn until the last check between the first two irrigating ditches has been filled. The surplus water from the last check may be disposed of into a drain or into lower irrigation canals according to local circumstances.

When all the land between the upper two irrigating ditches has been flooded water is turned into check No. 8. Should full heads of water be available for both of the ditches to the right and left of check No. 8, then the flooding of 9 and 15, 10 and 16, etc., may proceed simultaneously, otherwise irrigation should proceed in the order in which the checks are numbered in the diagram. On sandy soil or sandy loam the time required to fill a check should not exceed three hours, otherwise there will be great waste of water. If a check can not be filled in this time its size has not been properly adapted to the available head of water. Either the check is too large or there is not enough water turned in.

On heavy soil, which does not take up water so rapidly as sandy soil, time to fill a check should not exceed twenty-four hours. In practice some checks are made very large up to 60 acres in area and the amount of water turned in to flood them has been as great as 250 cubic feet per second. Such areas in one check are not advisable and should be regarded merely as temporary features of a very extensive irrigation system.

Checks with areas of 8 to 10 acres are large, and preferred sizes are 2 to 5 acres.

The embankments in use for irrigation by this method may be temporary or may be permanent. If temporary they are plowed down after irrigation so as to avoid obstructing farming operations. If permanent they may either have the profile shown in Fig. 4 or that in Fig. 5. Sometimes they are made even steeper, with still narrower crest than that indicated in Fig. 5.

The flat profile indicated in Fig. 4 is rapidly finding favor. It is the only one which can be recommended. The flat levee does not interfere with any farming operations; it is plowed and cultivated just the same as any part of the field and generally produces the best crop. It is constructed by plowing the ground to the right and left of the levee center in a strip 80 to 100 feet wide. The ground loosened by the plow is scraped toward the center and will be found sufficient for such levees as are ordinarily required. Alfalfa and grain are the crops ordinarily irrigated by flooding in contour checks.

The cost of preparing land for this method of irrigation in permanent checks ranges from \$2.50 to \$5 per acre, and the cost of the necessary distributing canals, ditches, and structures from \$3 to \$5 per acre, and the cost of the necessary distributing canals, ditches, and structures from \$3 to \$5 per acre. These figures, of course, may be greatly exceeded if the ground's surface has too great a slope or is very much broken by hog-wallows, or swales and ridges. Irrigation by this method is much less expensive than by wild flooding. The only labor required of attendants is the opening and closing of gates and the guarding of the check levees. When ground is well prepared for this method of irrigation, and the supply of water is abundant, the cost of each application of water will range from 3 to 30 cents per acre. The best examples of irrigation by this method are found on Kern Island, on the Calloway Canal; on Buena Vista farm, watered by the Kern Valley Water Company's canals in Kern County; near Borden and Madera, Fresno County; on the Columbia and Chowchilla ranches irrigated by the Chowchilla canal; on the west side of the San Joaquin Valley, and at various points in the Sacramento Valley.

FLOODING IN RECTANGULAR CHECKS NOT LEVELED.

[See Plate No. 3.]

When the surface of the ground is sufficiently smooth it is frequently possible to substitute a system of rectangular checks for the irregular shaped checks of the contour levee system. This may be done either by placing the main check levees as nearly parallel to the contour lines as possible, or by adapting the exterior lines of the checks to any desired course regardless of the direction of the greatest slope of the ground's surface. In this system of irrigation the main levees, as well as the cross levees, must have a varying height. In this respect it differs materially from the contour check system where the dimensions of the main check levees are uniform.

The dimensions of the levees are most variable when the levee lines

Flooding in Rectangular Checks. (not level)

Fig 1 Plan

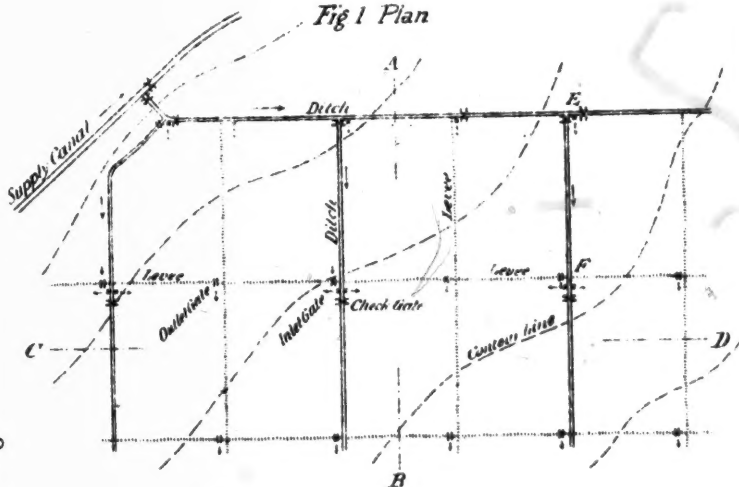


Fig 2. Section AB (distorted)



Fig 3. Section CD (distorted)



Fig 4. Detail at E.

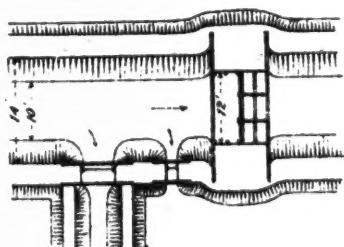
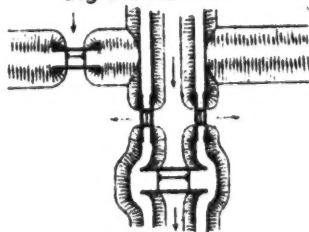


Fig 5. Detail at F.



*Example of
Flooding in Contour and Rectangular Checks
without levelling.*

(Kohler, West and Minturn)

Fig 1 Plan.

Sec 13, T 9 S R 15 E

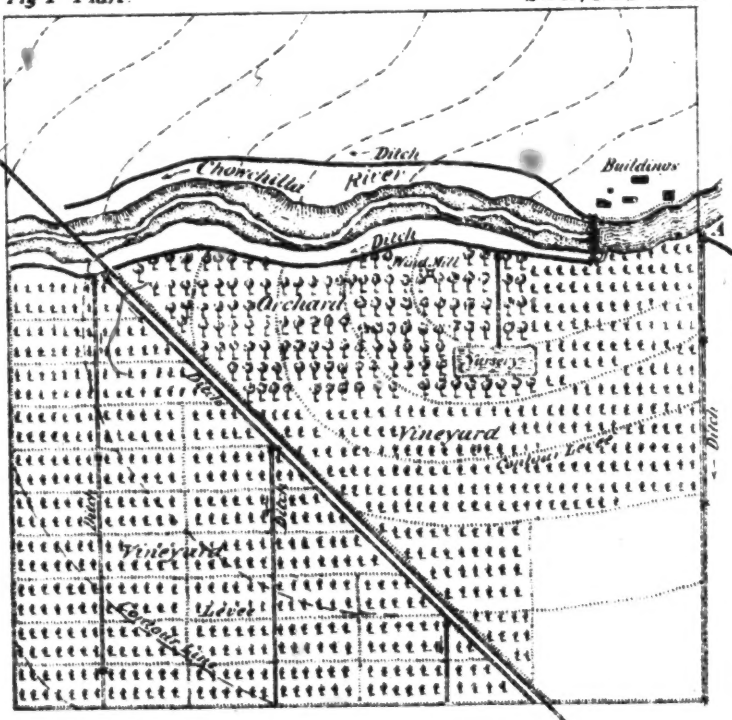


Fig 2 Gates at A.

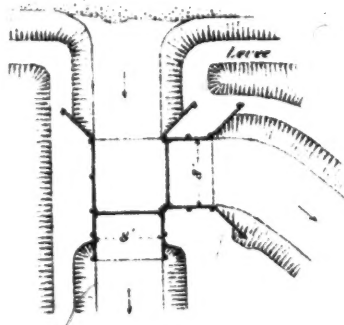
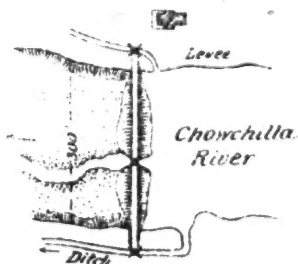


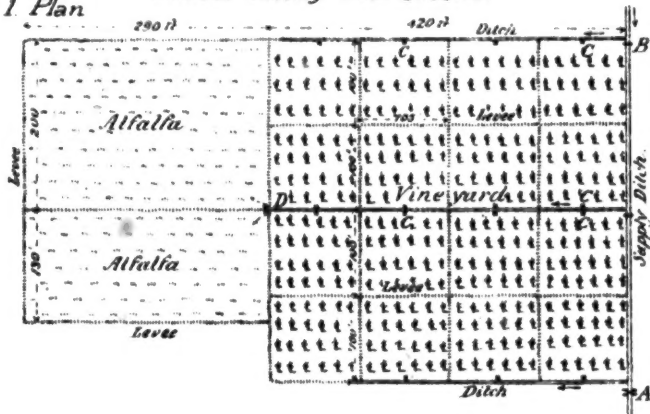
Fig 3 Dam in Chowchilla River



Flooding in small level Checks

Central Colony near Fresno.

Fig 1. Plan



Movable Check-Gate at B.

Fig 2. Elevation.

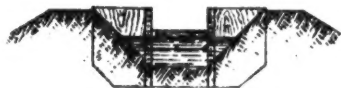


Fig 3. Plan



Inlet at C.

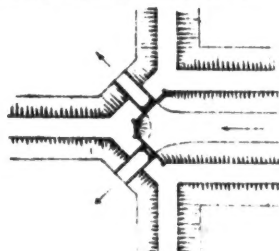
Fig 4. Vertical Section.



Fig 5. Horizontal Section.



Fig 6. Ditch and Gates at D.

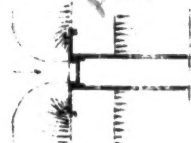


Inlet-Gate at D

Fig 7 Section



Fig 8. Plan



Irrigation by filling Subsoils with water.

Mussel Slough Country.

Fig. 1 Plan

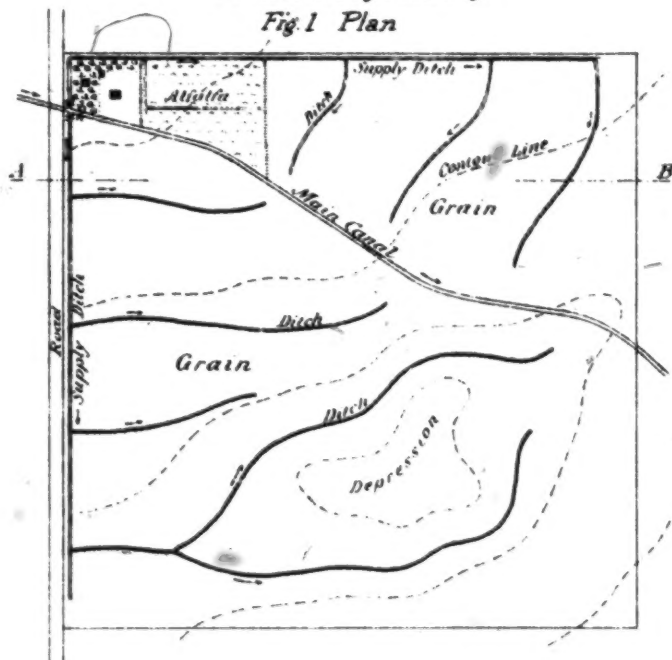
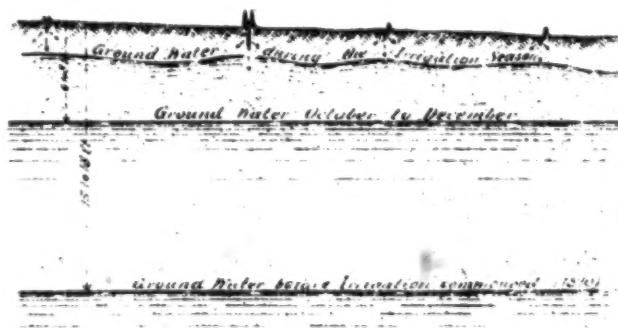


Fig. 2. Section AB.



are adopted arbitrarily without regard to direction of contour lines. This system of irrigation is illustrated by diagrams on plate No. 3. Ground is supposed to slope gently from the upper left-hand corner of Fig. 1 to the lower right-hand corner. The highest point of ground in each compartment or check is therefore in the upper left-hand corner. All levees as well as ditch banks must be higher above the surface of the ground at the lower right-hand corner of each check than at any other point. The size of the compartment must necessarily be smaller than would be required for contour levees unless the ground's surface be very flat. But the method of applying water after the ground has been once prepared is the same as for flooding in contour checks. The system of flooding in rectangular checks has the great advantage of permitting levees and ditch lines to be adapted to the direction of rows of trees, vines, etc., and it ought to be adopted whenever the configuration of the ground will permit.

Attention is drawn in this connection to the Kohler, West & Minturn tract, at Minturn, at Chowchilla River, Fresno and Kern counties. (See Plate No. 3.) At the time this tract was visited, in 1884, most of it had been set out to trees and vines. Irrigation was accomplished by water diverted from Chowchilla River. Part of the tract is prepared for irrigation by the contour check method, the rest by the rectangular check method.

The rectangular checks are arranged as indicated in the plan (Fig. 1). They are about 660 feet long east and west by 330 feet north and south. The method of admitting water and drawing it off from each check into the next lower one as soon as the flooding of the check has been accomplished, is the usual one already described. Water is supplied by distributing ditches, arranged about as indicated in Fig. 1.

In Fig. 3 the general arrangement of the works for the diversion of water is indicated, and Fig. 2 will explain the arrangement of the head gates in the various distributing canals. The soil of the Kohler, West & Minturn tract is a light sandy loam. Under it lies a hardpan which is quite near the surface at the eastern line of the tract, but its dip westward is greater than that of the surface of the ground. The ground water is about 14 feet below the surface.

When irrigation is in progress with a full head of water (about 16 cubic feet per second) 6 men are required to manipulate gates and guard check levees. Attendants work in two shifts of three, each for twelve hours. Where the levees are constructed on contours the area of the several checks is variable, the largest covering about 20 acres of ground. The contour levees are in 6-inch contour lines. All these are made sufficiently high to retain water to the depth of 1 foot.

Irrigation, while contour checks are being flooded, progresses at the rate of about 40 acres per day of twenty-four hours, and at the rate of 20 acres per day while the land covered by rectangular checks is being irrigated. The greater time required in the latter case is due to the two causes, that the soil in these checks is deeper than at points east of the railroad, and that water used for its irrigation is generally subdivided, being made to irrigate a number of checks at the same time, whereby in porous soil unnecessary loss of water is always entailed.

FLOODING IN LEVEL CHECKS.

[See Pl. No. 5.]

In some localities where the surface of the ground is neither sufficiently smooth nor sufficiently level to permit an application of water by either of the methods already described without too great an expense,

another method of flooding has found favor. Such has been the case near Fresno. It has there become customary to prepare land for flooding by constructing rectangular checks and making the area inclosed by each rectangle of levees as nearly level as the nature of the soil would permit.

Size and relative length of the sides of the rectangular checks are always to be governed by the peculiar character of the ground's surface. It is evident that if the checks be made very long in the direction of the slope of the ground, it may become necessary to move a very large amount of material from the highest end of a check to its lower end. Very frequently the entire work of leveling consists in the cutting down of knolls and the depositing of the material thus obtained in the low places of the check and along the line of the embankment which is to surround it. It sometimes happens, as on the sandy plains in the Fresno district, that when water is applied to the land for the first time the soil is compacted, the surface settles. This settling may be quite regular, but ordinarily it is irregular, and not infrequently a caving in of the surface soil occurs in spots, leaving cavities sometimes 20 or more feet in diameter and 4 to 10 feet deep to be refilled after the first thorough wetting. Where such caving in has occurred it is quite evident that the complete leveling of the ground's surface can often be accomplished by a judicious selection of the points from which to take material for the purpose, with as little expense as a mere haphazard filling of the depressions would entail. Where the surface of the ground is of the peculiar knolly character generally termed "hog wallow" the same is true.

An example of this method of irrigation has been taken from a tract in Central California Colony (Fresno County), and is illustrated on Pl. No. 5. The plan (Fig. 1) represents the ditches and levees required to accomplish the irrigation of sixteen small checks of vines and two larger checks of alfalfa. Water is supplied by the ditch B A. It is distributed to the several checks by the ditch C D and parallel ditches. Low levees very flat, just high enough to hold with reasonable safety about 4 inches of water, surround each check. Between each two small ditches, C D, are two rows of checks. Each of the vineyard checks has an area of about one-fourth of an acre. The alfalfa checks are larger, the area of one being about $1\frac{1}{4}$ acres, that of the other three-fourths of an acre.

The irrigation of any row of vineyard checks is accomplished by checking the flow of the water in the main ditch below an irrigating ditch, as at B, and admitting the water in turn into the several checks which are to be supplied from the irrigating ditch. Irrigation, except in the case of very impervious soils, will ordinarily be complete as soon as water has been made to cover all the ground of any check to a depth of 1 or 2 inches. The more pervious the soil the more important will it be to supply a respectively large flow of water to each check. As soon as enough water has been supplied to any check the inlet gate, opening from the distributing ditch into another check, is opened and the gate leading into the former check is closed.

Wherever on sandy loam more than three hours' time is required to thus supply enough water to any check, then there is something wrong in the method of applying water. Either the size of each check ought to be reduced or the supply of water increased.

In 1882 an irrigator was observed who was engaged in irrigating four small checks of alfalfa. His water supply was small, only about 2.26 cubic feet per second. Instead of turning all the water in turn into the

several checks he apportioned it to the four and the time to fill them was ten hours, whereas not more than an hour apiece would have been required had they been filled one after the other.

Returning to the example of irrigation illustrated on Pl. No. 5, it is evident that the flow of water in the ditches can be checked either by means of small gates or by means of temporary dams of earth thrown in with a shovel during the process of each irrigation. A movable check gate of very simple construction is shown in Figs. 2 and 3. It consists in the main of a notched board with narrow strips nailed to it on either side of the notch, and a set of loose pieces of boards whose ends can be slipped down the grooves formed by the strips for the purpose of closing the notch. A check gate of this character can be set across a ditch at any point where it is required in a very minutes. It can be made more secure than it would otherwise be by nailing to its lower margin and to its sides a strip of canvas to be imbedded in the material used in refilling the excavation made to receive the gate. A permanent gate as at A can be arranged as already explained by Figs. 5 and 6, Pl. No. 1.

The inlet gates at C from the small ditches to the several checks are arranged in the form of a small culvert, as shown in Figs. 4 and 5, Pl. No. 5, or they have the form represented in Figs. 7 and 8. The arrangement of levees, ditches, and gates at the point D of Fig. 1 is made clear by Figs. 6 and 7.

No drainage is combined with this method of irrigation. All the water admitted into a check is absorbed by the soil. It is to be noted in connection with the experience of the early irrigators near Fresno, that the quantity of water absorbed by or rather percolating through the soil was at times enormous. Instances have been recorded where enough water has been run on to a 20-acre tract at one wetting to cover the tract to an average depth of 5 feet, and examples can be cited where the quantity of water supplied in one season would have been sufficient to fill a reservoir of the same area as the tract irrigated 20 feet deep.

The preparation of land for irrigation by flooding in level checks is much more expensive than the preparation of land for irrigation by any of the other methods already described.

It costs about \$15 to \$50 per acre to put the surface in proper shape and to construct the necessary ditches and gates. But the application of water when once preparation for it has been properly made is far less expensive than by other methods, and this method of irrigation enables a very economical use of water, because the wastage by unnecessary percolation into subsoils is reduced in the same proportion that the time required to fill individual checks is reduced.

IRRIGATION BY FILLING SUBSOILS WITH WATER.

[See Plate No. 7.]

It is not infrequently claimed that large tracts of land are irrigated by lateral percolation of water from canals or ditches. As a matter of fact lateral percolation does not extend more than a very short distance from a water course, unless the same supplies water to a very pervious soil resting on a subsoil of clay or other impervious material. The phenomenon of the wetting of the soil at some point remote from the water course which supplies the water is ordinarily due to a very different cause. Where the surface of ground water is very nearly level the effect of an additional supply of water to subsoils by downward

movement of water from canals and ditches will be to cause it to rise to a higher plane. It will rise most rapidly at those points where most water sinks into the ground, but its rise may extend over a very large area of country. The hydrostatic pressure exerted by the sinking water extends in all directions, and may cause a displacement and a rise of water even at very remote points. If water sinks into pervious subsoils at many points throughout a relatively flat region it may cause the subsurface water to rise sufficiently to bring moisture from below within reach of the capillary and hygroscopic forces of surface soils.

This occurs in the Mussel Slough country and it has become the common method of irrigation in that region. The same phenomenon is observed near Fresno and at other points north of Kings River.

The method of irrigating by filling subsoils with water, as practiced in the Mussel Slough country, is illustrated on Pl. No. 7. Fig. 1 represents the plat of a tract of 160 acres. In the northeast corner is a small orchard and an alfalfa field of a few acres. The alfalfa is inclosed by a levee, so that at least once a year it may be flooded in order to exterminate gophers. A main canal passes through the tract, and from this distributing ditches are diverted and carried down along the west and north lines of the tract. About 600 feet apart small irrigating ditches lead out from the distributing ditches. These have a very slight grade in order that water may be kept at a sluggish flow in them during the irrigating season.

As soon as water becomes available for irrigation it is turned into all the ditches (which may be permanent or temporary), and the depth to ground water of October to December, as shown in Fig. 2, is gradually decreased until water is everywhere found at a depth of only a few feet below the surface. As soon as irrigation is complete water is no longer admitted into the irrigating ditches, and the depth to water begins to increase slowly. By careful inquiry it has been ascertained that before irrigation commenced, that is, before 1870, the depth to ground water ranged everywhere in this region from 15 to 18 feet. Except on the extreme edges of the region it no longer falls lower than 8 feet below the surface in the fall of the year. During the spring and early part of the summer it is held by reason of the presence of water in the irrigation ditches within 2 to 4 feet of the surface.

It will be seen that, where this method of irrigation is practiced, lands lying between irrigated tracts may derive a full benefit from irrigation without being taxed to contribute to the establishment or maintenance of the irrigation system. The mere fact that the water has been permanently raised from 18 feet below the surface to 8 feet below the surface may in many instances be a great benefit.

The system of applying water to the soil from underneath has the advantage of being very inexpensive. It is, however, open to serious objection when soils or subsoils contain much alkali. In such cases alkaline salts are carried upward by the upward moving water and their accumulation at the surface is the natural result. Many of the irrigators in the Mussel Slough region testify to such rise of the alkali, and to the fact that salt grass is crowding the alfalfa, and has not infrequently usurped parts of grain fields.

IRRIGATION FROM FURROWS.

Not the least important method of applying water to land is that which is ordinarily called furrow irrigation, and which is almost universally adopted for the irrigation of orchards, vineyards, cotton, hops, vegetables, or other plants that may to advantage be set out in rows.



Furrow Irrigation of Grain.

Fig 1. Furrows in the direction of greatest slope

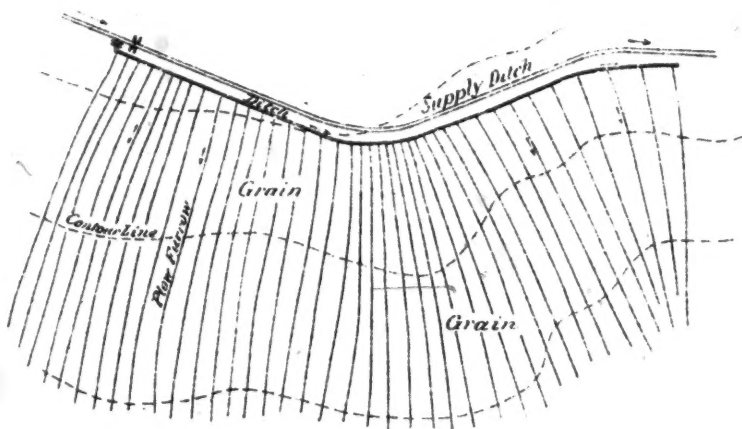
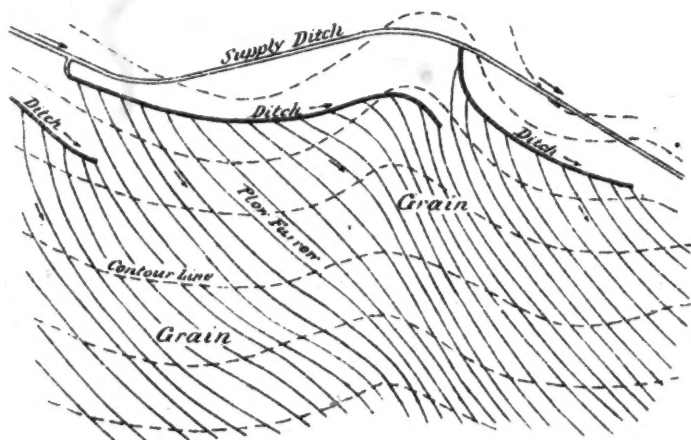


Fig 2. Furrows at less than greatest slope



By this method of irrigation it is aimed to moisten only those layers of soil into which the roots of trees and plants penetrate. Surface drainage is sometimes combined with this method of irrigation. More frequently, however, no attention is paid to drainage, the aim being to introduce into each furrow barely enough water to accomplish the desired end.

This method of irrigation can be best described under the following heads:

Furrow irrigation of grain—

- (a) With furrows in the direction of greatest slope.
- (b) With furrows across the direction of greatest slope.

Furrow irrigation of orchards, vineyards, etc.—

- (a) With drainage.
- (b) Without drainage.

Furrow irrigation in leveled checks.

Furrow irrigation of vegetables.

Furrow irrigation of hillside orchards, etc.

All of these special cases have been illustrated with diagrams, to which reference will be made in describing each.

FURROW IRRIGATION OF GRAIN WITH FURROWS IN THE DIRECTION OF GREATEST SLOPE.

[See Plate No. 6, Fig. 1.]

Even when water for the irrigation of grain land is available, the farmer is not inclined to burden himself with the additional expense of applying water to land so long as he may hope to have sufficient rainfall to mature his crops. In the most extensively irrigated region of the San Joaquin Valley the average annual rainfall is about 10 inches. This is sufficient to produce good crops if the rain falls at the right time. It does not always do this, and moreover the total rainfall is just as frequently below the average as above it. Consequently it often happens that water must be artificially applied in the spring of the year to refresh the parching fields of grain. If the same be prepared for flooding this method of irrigation will be resorted to. Should it be situated in a region like the Mussel Slough country, ditches will be kept full of water, and perhaps a few new ones will be constructed to hasten the rise of ground water. But if the same be not thus favored, then the question arises how to apply water to its surface most rapidly. The method which in some localities, as for instance near Kingsburg, has found favor, is that of irrigating in parallel furrows. The same method has there also been successfully practiced for the wetting of ground before it was plowed and the seed sown.

If the slope of the ground's surface be not too great, the furrows, which are generally deep single furrows, are run in the direction of the slope. They are placed 8 to 12 feet apart, according to the porosity of the soil. Water is admitted into them from small ditches, generally crossing them at intervals of 100 to 200 yards. The irrigation commences at the highest part of the field. Water is admitted into a number of furrows at one time, and by attendants this flow is checked or aided so as to accomplish a general soaking of the ground's surface. It is thus aimed to wet all parts of the field. This system of irrigation involves much labor and careful watching. It is relatively expensive.

FURROW IRRIGATION OF GRAIN WITH FURROWS ACROSS THE DIRECTION OF GREATEST SLOPE.

[See Plate No. 6, Fig. 2.]

This method of irrigation is analogous to that just described, except that, owing to too great slope of the surface of the ground, the plow furrows are run on predetermined grade lines. The greater the slope of the surface the greater must be the deviation of the furrows from the direction of the greatest slope. Ordinarily no attention is paid to properly draining the field irrigated in this way, it being the aim of the irrigator to supply just enough water to accomplish the wetting of the surface soil.

The furrows used for the distribution of water to accomplish the irrigation of grain land are, as soon as irrigation has been accomplished, plowed in, so that they may not interfere with subsequent farming operations.

FURROW IRRIGATION OF ORCHARDS, VINEYARDS, ETC., WITH DRAINAGE.

[See Figs. 1 and 2, Plate No. 8, and Fig. 2, Plate No. 9.]

Whenever any plants set out in rows are to be irrigated the natural method of applying water to the soil is that of conducting it in furrows between the rows. In this method of irrigation, when rows are far apart, it may sometimes be advisable to draw a furrow for water upon each side of every row of trees or vines. Ordinarily, however, one furrow between each two rows of trees or vines is preferred.

Furrows are generally made by plowing between rows away from the center, thus raising the ground near the rows, lowering it midway between them. The work of plowing is finished by making the last furrow a double furrow. Sometimes ditch machines, prepared especially for the purpose, as, for instance, a long log with a wedge-shaped head, are drawn through the plow furrows to finally prepare them for water.

This method of irrigation can best be explained by reference to Plate No. 8, Fig. 1. The ditches supplying water are there represented by double lines or by single heavy lines. From these water is admitted into the furrows between the rows of vines, trees, hops, or cotton, as the case may be. Care is taken to admit it at the same time to a sufficient number of furrows to reduce its flow in each, so that no washing of the soil will result. At the lower end of each furrow the water collects in a small drain ditch, which carries it off for further use. It is allowed to flow through each furrow long enough to permit a sufficient percolation into the loose soil along its course. The application of water should always commence at the highest point of the field to be irrigated. Furrows are not generally more than 300 feet long, unless the ground's surface be unusually smooth and the soil quite impervious.

FURROW IRRIGATION OF ORCHARDS, VINEYARDS, ETC., WITHOUT DRAINAGE.

[See Fig. No. 3, Plate No. 8.]

It frequently happens that the soil to be irrigated absorbs moisture so fast that there is little or no danger of supplying water to any particular spot in the field to be irrigated in so great quantity as to do injury to the plants there growing. It has therefore become a common practice to irrigate with furrows from the highest points of a field

Furrow Irrigation of Vineyards and Orchards.

Fig 1 With Drainage.

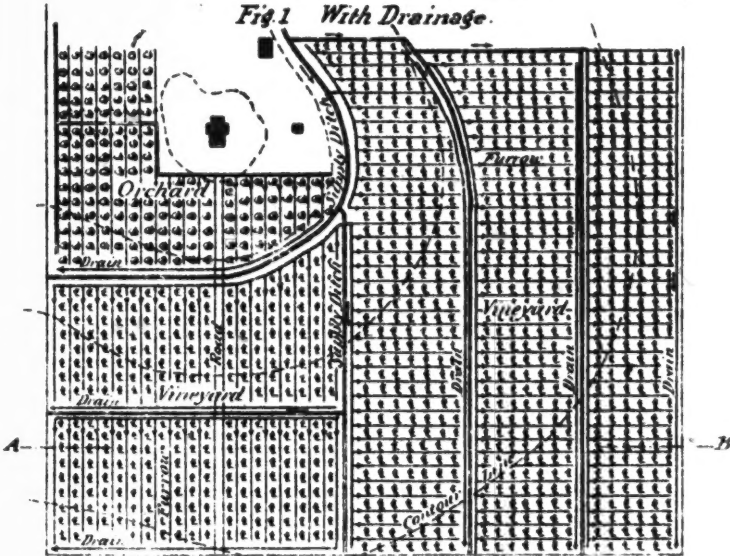


Fig 2 Section AB.

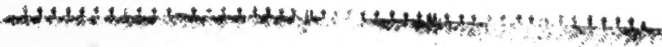
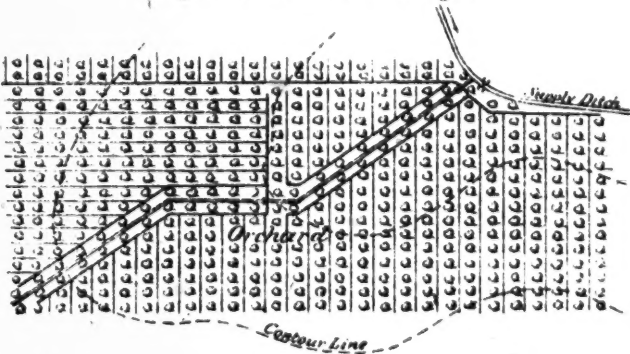
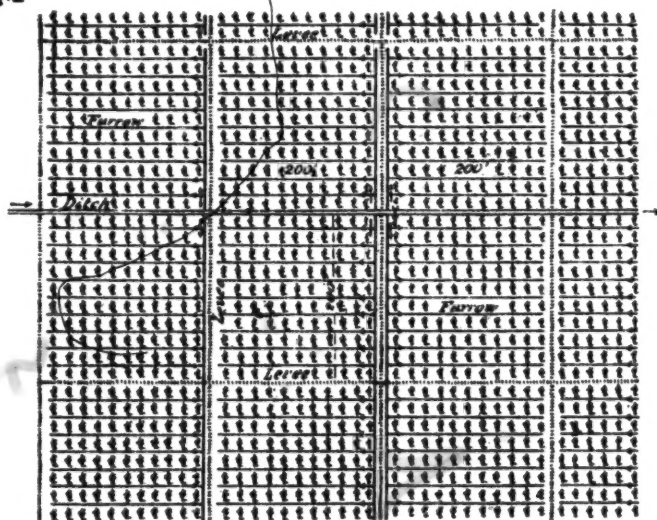


Fig 3 Without Drainage.



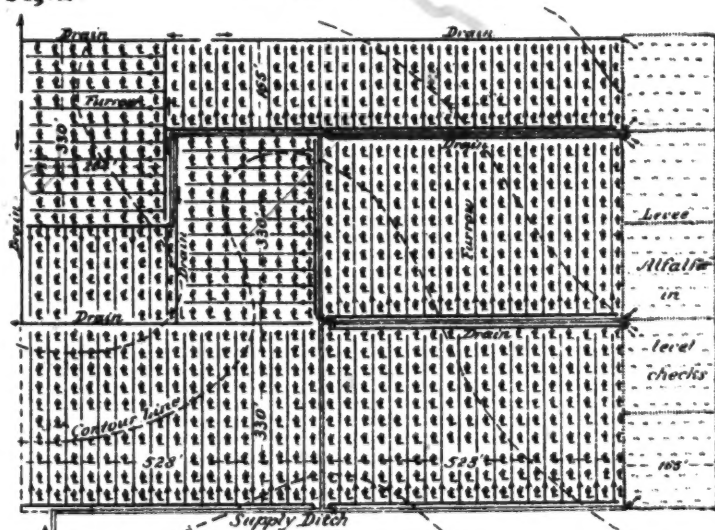
Furrow Irrigation of Vineyards in level Checks.

Fig. 1



Furrow Irrigation with Drainage. Vineyard near Fresno.

Fig. 2



Hillside Irrigation

Furrow System

Orchard near Porterville

Fig 1.

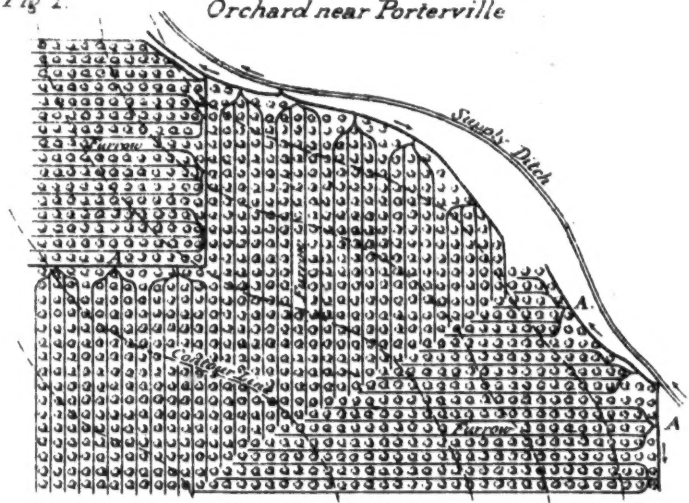


Fig 2. Detail at A.

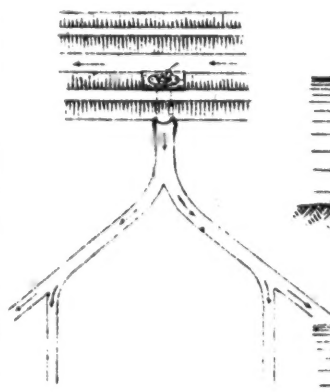
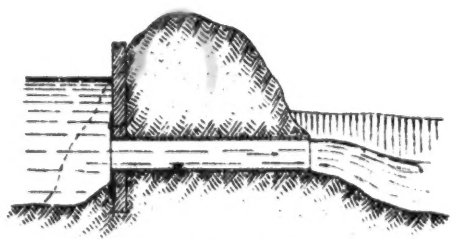
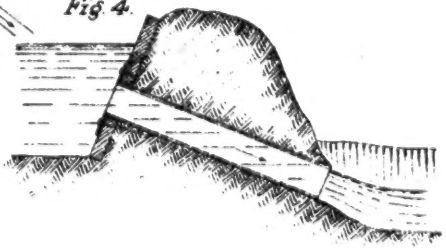


Fig 3.



Furrow Inlet Tube

Fig 4.



Irrigation of Vegetables, Berries, or other Crops closely set in rows.

Fig 1. Plan.

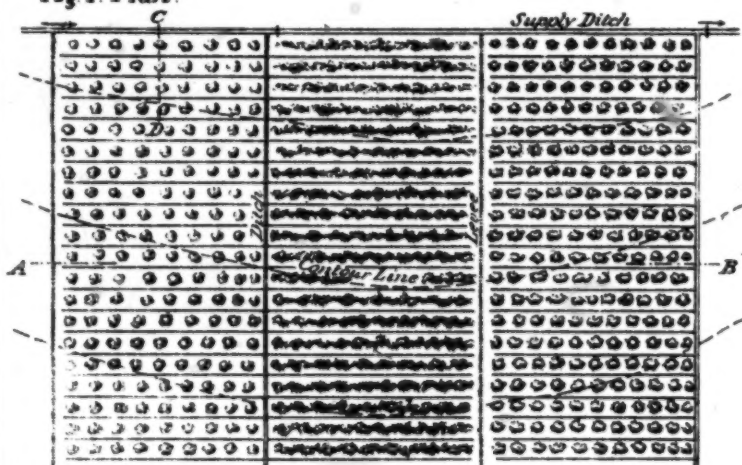


Fig 2

Section AB.



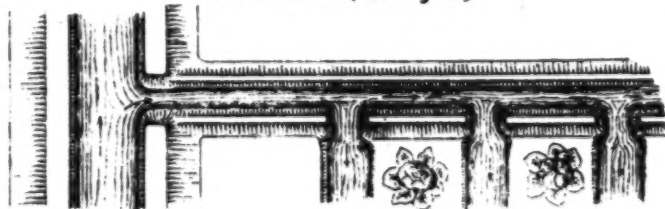
Fig 3.

Section CD (enlarged)



Fig 4

Part of Plan (enlarged)



toward the lowest, without making provision for drainage. Ditches and furrows are arranged as indicated in Fig. 3, and great care is taken to admit no more water into each furrow than will just wet it from end to end.

FURROW IRRIGATION IN LEVELED CHECKS.

[See Fig. 1, Plate No. 9.]

When a few years ago it was feared that the ravages of the phylloxera might be extended into the vineyards of Fresno County it was deemed advisable by some vineyardists to set out all vines in checks which could be completely submerged. Fortunately such submersion to combat the phylloxera has never become necessary. But the preparation of the ground which had been made led to a new method of applying water to the land. From a supply ditch, water is admitted into a small ditch upon one side of each check, and from this small ditch it enters deep horizontal furrows, which have been drawn between each two rows of vines. As soon as water has filled all the furrows, irrigation is complete and the head of the check ditch is closed.

FURROW IRRIGATION OF VEGETABLES.

[See Plate No. 11.]

When irrigation must be more frequently repeated than in the case of orchards, vineyards, etc., as in the case of vegetables, the surface of the ground is more thoroughly prepared for the reception of water; the handling of the water is simplified. It is customary to set out most vegetables, strawberries, etc., in rows that are close together. Each row is on a ridge of ground from a few inches to a foot in height. Each row is short, varying from 5 to 20 yards. Water is supplied to a tract of vegetables in a ditch located on the highest ground. Thence at right angles to the direction of the rows of vegetables branch ditches lead through the tract past the end of the rows. Each row of vegetables and the depression between it and the next row are horizontal. Water is admitted from the small irrigating ditch to the furrow or depression between the rows to the right and left, being checked at convenient points in the irrigating ditch until all furrows above these points have been filled with water. Surplus water standing in the furrows when gates and dams have been removed will, to some extent, find its way back into the irrigating ditch; the rest finds its way into the soil. The arrangement of ditches and levees necessary to accomplish this irrigation is made fully apparent in Figs. 1, 2, 3, and 4 of Plate No. 11.

FURROW SYSTEM OF HILLSIDE IRRIGATION.

[See Plate No. 10.]

Without attempting an elaborate discussion of the best methods of irrigating hillside lands, it is desired to call attention here to a method employed by an intelligent irrigator on a moderately steep hillside set out to fruit trees a few miles above Porterville, in Tulare County. The soil was of the nature of dry bog, very dark in color, sticky when wet, cracking and crumbling when dry.

The supply ditch followed a grade line around the hillside above the orchard. At selected points it was tapped by smaller ditches, which

carried the water along the hillside, below the main ditch, on a somewhat greater grade. Into the lower banks of these irrigating ditches tin tubes were imbedded, fitted into headboards resting against the inner side of the ditch bank, as shown in Figs. 2, 3, and 4 of Plate No. 10. These tubes were in use to obviate the necessity of cutting the ditch banks and to prevent the washing out of cuts in these banks, which would result if the tubes were not in use. They are only temporary features in the bank, being removed as soon as they are no longer required at any particular point.

These tubes can be made of any thin material, like galvanized iron or tin, which can easily be bent into the desired form. The great advantage of using some contrivance similar to these tubes is the ease with which the amount of water taken from the ditch at any point can thereby be regulated.

The water delivered through each tube was subdivided into three or four furrows, drawn as indicated in Fig. 1, between each two rows of trees, through a well-plowed and well-pulverized soil. One attendant, without any hard labor, could keep small streams trickling down thirty furrows at one time. After irrigation the entire surface layer of the soil of the orchard was wet, and much water had penetrated into the substrata of soil.

IRRIGATION FROM SUB-SURFACE CONDUITS.

[See Plates Nos. 12 and 13.]

This method of applying water to land has not been as satisfactory as it was hoped by its friends that it would be, but having been introduced in some localities on a large scale it can not here be passed without a notice.

The intent of this method of irrigation is to supply a moderate quantity of water directly to those parts of the soil where moisture is needed without wetting the surface of the ground. Thereby it was hoped to economize water, to greatly simplify its distribution and control, to cheapen irrigation, and to avoid the baking of soil and the necessity of breaking up its surface after each application of water.

The system of sub irrigation which has generally found favor is illustrated on Plates Nos. 12 and 13. It is essentially a pipe system. Water is distributed to all parts of the land to be irrigated in cement pipes, from which it escapes through perforated plugs of wood. It is admitted into pipes under a low pressure, sufficient to insure the escape of some water even in the highest parts of the land to be irrigated. The system is applicable only to smooth surfaced tracts having but a slight slope.

The final distributing pipes are constructed by means of a peculiar machine. They are made in place and are continuous. The diameter of their bore is 2 inches. At intervals corresponding to the distance between trees or vines they are perforated from above and a wooden plug with a hole lengthwise through it is inserted in the perforation. This plug is protected by means of a hollow cap or earth guard resting loosely upon the pipe over it. (See Figs. 9 and 10, Plate No. 13.) The pipe is placed 20 inches or more below the surface of the ground so as not to interfere with plowing, cultivating, etc. Water is conducted to the 2-inch pipes, which may be laid between each two rows, if rows be far apart, as in the case of trees, or between alternate rows, if they be close together, as in the case of vines, by means of a system of 6-inch

Sub-Irrigation.

Fig 1. General Plan for Vineyard and Orchard.

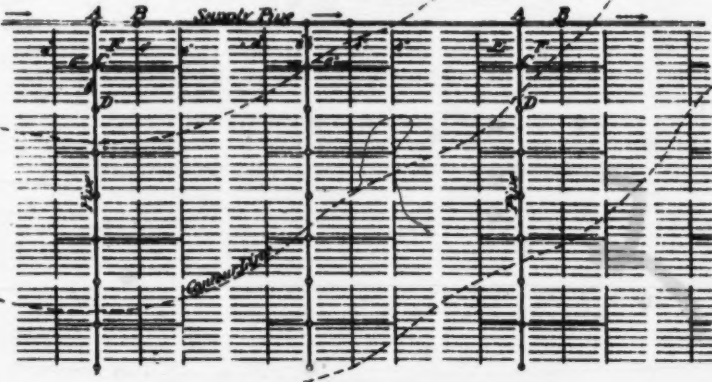


Fig 2. Plan of Block 'E' - Vineyard.

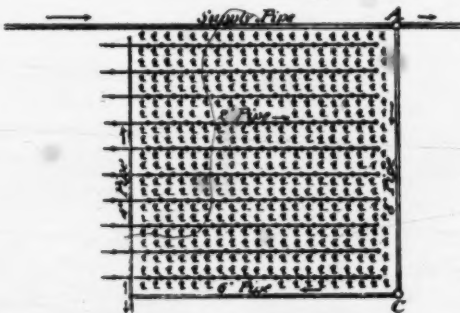
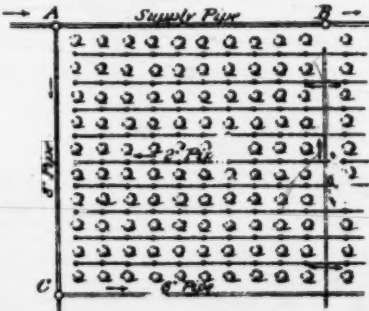
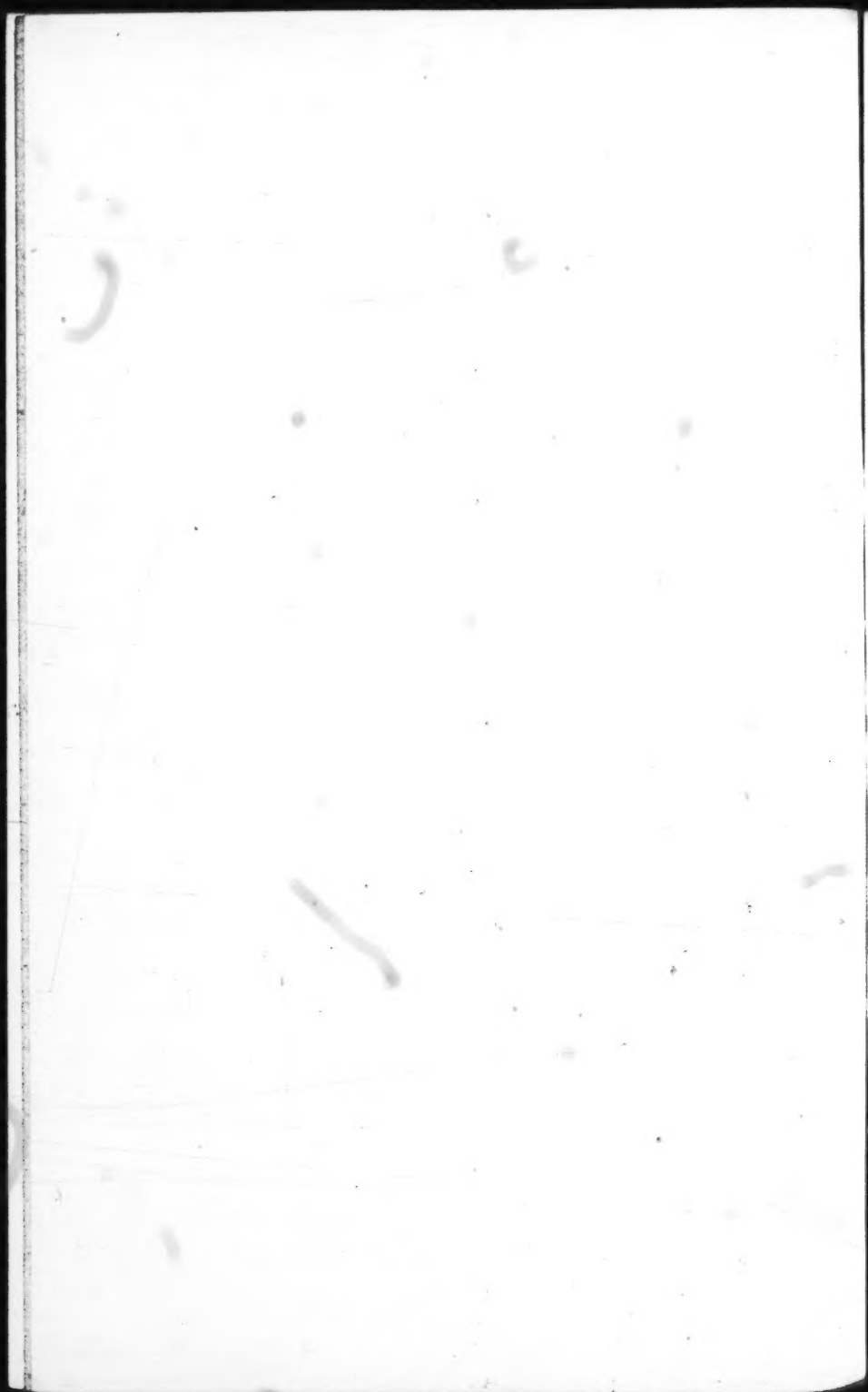


Fig 3. Plan of Block 'F' - Orchard.





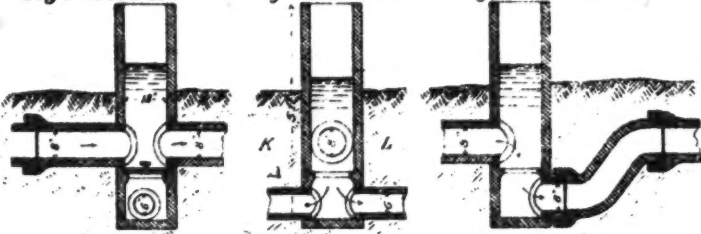
Sub-Irrigation

Details.

Fig 1 Section GH.

Fig 3 Section IJ.

Fig 5 Section MN.



Hydrant at C.

Hydrant at B and D.

Fig 2. Plan

Fig 4 Section KB.

Fig 6. Plan



Fig 7. Section and Elevation of 2 inch Pipe



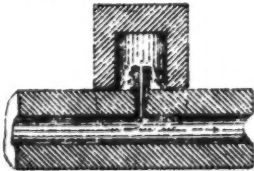
Fig 8. Plan of 2 inch Pipe and Earth-Guards



Sections of Earth-Guard (enlarged)

Fig 9 Section OP.

Fig 10 Section QR.



Pump Irrigation.

James Rutter, Florin, Sacramento Co.

Fig 1. Section AB.

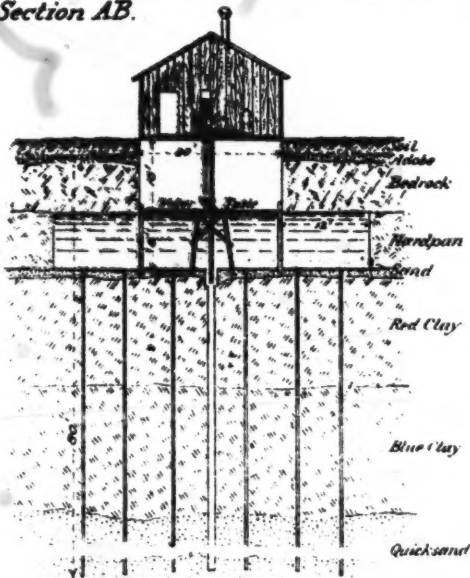
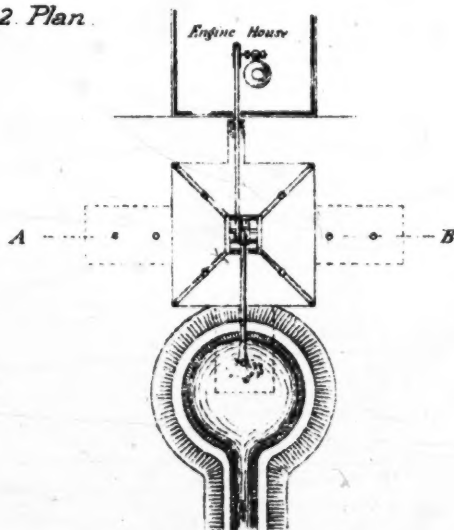


Fig 2. Plan.



and 4-inch pipes, which in turn receive water from a main supply pipe, generally about 8 inches in diameter.

The illustrations given on the two plates already referred to show a possible arrangement of the pipes, etc., for the irrigation of vineyard and orchard land. In Fig. 1, Plate No. 12, an 8-inch supply pipe follows the line AA BB. From it branch off in the direction ACD 8-inch pipes, which convey all the water in turn to the several tracts to be irrigated. From the branch pipe lines ACD, at the points C, 6-inch pipe lines carry off the water and distribute it to a number of 4-inch pipes, and these in turn to the final 2-inch pipes.

At all points where 8-inch and 6-inch pipes branch, so-called hydrants are introduced as shown in Figs. 1, 2, 3, 4, 5, and 6, by means of which the water may be shut off from one line or the other of pipe. The hydrant represented in Figs. 5 and 6 illustrates the means of checking the flow of water in a pipe main. In the drawing the pipe is represented as open. It can be closed by inserting a disk and resting the same on the projecting rim around the hydrant below the mouth of the inlet pipe and above the head of the outlet pipe. The hydrant shown in Figs. 1 to 4 will enable the closing of the 6-inch pipe system from the 8-inch line, but it does not enable a closing of the 8-inch line and a forcing of all water into the 6-inch pipes.

When water is to be supplied to any part of a vineyard or orchard, as, for instance, to the six blocks commanded by the two 6-inch pipes which leave the 8-inch pipe line at C, then it is first necessary to close the hydrants at B and D. All water arriving at A must flow into the pipe toward C, and thence into the 6-inch pipes, 4-inch, and 2-inch pipes until they are all full. It will escape from the plugs into the ground and must be supplied fast enough to stand in the hydrants everywhere above the highest parts of the 2-inch pipe system, so that there may be no doubt that water is escaping from every plug in the tract covered by the 2-inch pipe system. As soon as irrigation from this system of pipes is complete the 6-inch pipes in the hydrant C are closed off and another set of pipes is brought into use.

Under favorable conditions it will cost about \$50 per acre to prepare ground for irrigation by this method. The roots of trees and plants will, notwithstanding every precaution to prevent it, find their way into the lines of pipes at exposed points and may seriously interfere with a successful irrigation.

Until irrigators are required to be very much more economical in the use of water for irrigation than at present, the matter of expense alone will interfere with any extended use of this system of irrigation.

EXAMPLES OF PUMP IRRIGATION.

On Plates 14 and 15 are shown a few examples of irrigation with water secured by pumping. The most interesting of the several examples is that showing the arrangement of a reservoir chamber and eleven wells which supply water to it, as carried out by Mr. James Rutter, at Florin, Sacramento County. From a large pit 25 feet square and 18 feet in depth, he drove three short tunnels into the hardpan, which was sufficiently firm to stand without lining. When the reservoir space had thus been made sufficiently large (about 5,000 cubic feet) eleven wells were bored to depths of about 80 feet. The central well has a 10-inch bore; the others are 4-inch wells. These wells supply water to the reservoir chamber, in which it rises to within 10 feet of the ground's surface. It is drawn from this chamber by means of a cen-

trifugal pump, which when run at full speed lowers the water table 8 feet in about five hours. About 80 acres are irrigated with water thus pumped on the Rutter place.

L. A. Oppenheim, Dr. W. A. Hughson, and others, near Florin, secure water for irrigation in the same way as Mr. Rutter, though generally the reservoir pit is circular in form, and one boring is relied upon to supply water to it. (See Fig. 1, Plate No. 15.)

W. B. Blowers, near Woodland, Yolo County, draws water from a large circular well or cistern 18 feet in diameter, lined with brick, which was sunk into a layer of gravel. Water is elevated by means of a centrifugal pump. (See Plate 15.)

ARTESIAN WATERS OF SAN JOAQUIN VALLEY.

In the foregoing pages reference has several times been made to the artesian wells in San Joaquin Valley. The results of my examination of nearly 300 of these wells, which was made for the State engineer department, have been presented in tabulated form in the book published by that department, entitled "Physical Data, etc."*

The source of supply for the wells of this valley is at the base of the Sierra Nevada, where waters sink from the rivers into layers of sand, which lie between layers of clay. This source of supply and the stratification of the valley as revealed by borings near Tulare Lake is shown on Plate 16.

A typical boring is shown on Plate 17, Fig. III, which shows the stratification as reported by the well-borer. In Figs. I and II on the same plate the arrangement of the reservoir or pond which is connected with the same well is shown.

The casing ordinarily used for artesian wells is of the double sheet iron type (Fig. IV), rarely of the screw joint pattern. (Fig. V.)

Loss of water from ordinary casing is illustrated in Figs. VII and VIII of Plate 17. The former represents the arrangement of a tank receiving water from a well on Kern Island. When it was found that much water was lost a box was sunk into the ground, and the leakage from three joints was found to be as much as the flow into the main tank. This leakage was brought to the surface by the box contrivance shown in the illustration.

Fig. VIII illustrates the arrangement at the artesian well which supplies water to Hills Ferry, Merced County. Leakage above the hardpan is sufficient to saturate the heavy clay soil, and to keep a small pond full of water.

Fig. IX illustrates the arrangement of the Cutler Salmon well about 8 miles southeast of Stockton. The inner casing (4 inches) supplies a large volume of gas, which rises with water that is strongly alkaline from a depth of 1,250 feet. The outer casing supplies potable water from a depth of 844 feet. The gas is used in the kitchen and throughout the dwelling for heating and lighting purposes. The potable water is conveyed to various points about the Salmon place in pipes. The saline water commingled with the other has a temperature of about 80°, and is used in public baths.

WATER MEASUREMENTS.

The necessity of delivering water to irrigators by measurement is beginning to be recognized. A unit of measurement is essential, and it will not be long before the "cubic foot per second," which is a defi-

*See Physical Data: Wm. Ham Hall, State Engineer, pp. 480-527.

Pump Irrigation.

*L. A. Oppenheim, Florin, Sacramento Co.
Section AB.*

Fig 1.

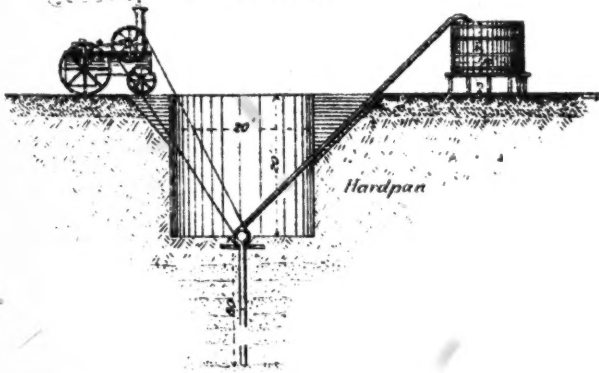


Fig 2 Plan.



W. B. Blowers, Woodland, Yolo Co.

Fig 3. Section AB.

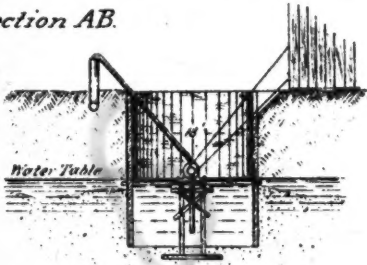
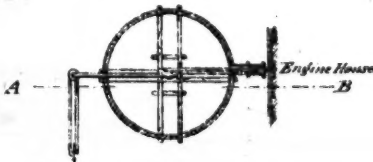


Fig 4. Plan.



Stratification of San Joaquin Valley

Fig 1

*Section from NE to SW,
through Tulare*

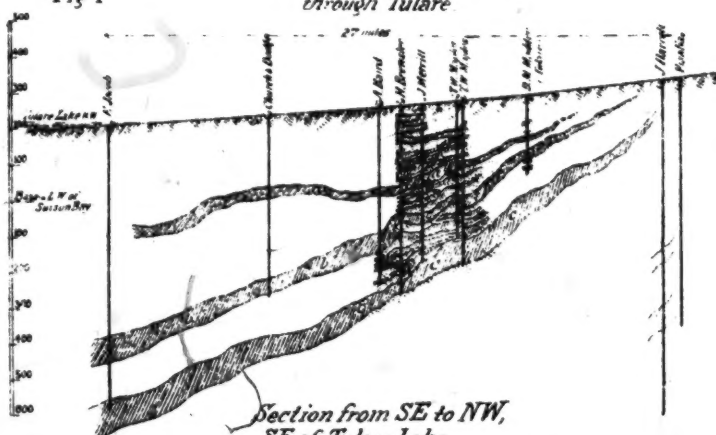


Fig 2

*Section from SE to NW,
SE of Tulare Lake*

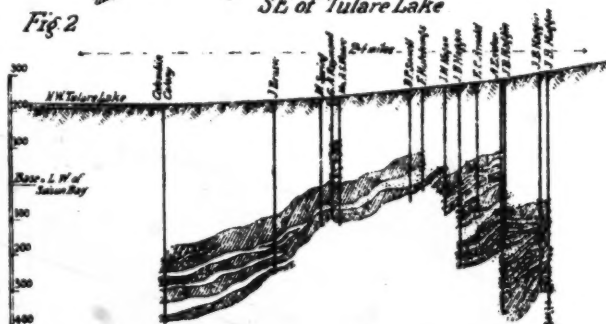


Fig 3

*Ideal Cross Section of San Joaquin Valley
through Tulare Lake,
showing Stratification*



nite quantity, will have superseded the "miner's inch" (which is no unit and defines a method rather than a measure) throughout California.

There have been but few satisfactory measuring boxes constructed in California, and in most cases at the present time water, when measured at all, flows through orifices under pressure. This method of measurement is always unsatisfactory, and ought whenever possible to be exchanged for weir measurement. I have endeavored to plan a measuring box which is adapted for use under conditions of water delivery as they generally prevail on the larger irrigation works in California, and have made a weir with clear overfall the basis of the water measurement. The contrivance is illustrated on Plate No. 18, and is shown in connection with a "checkweir" or "drop," as such structures are commonly arranged in the central portions of this State. The main canal in the diagrams is supposed to have a width of 24 feet; it may be of any width.

Its flow is checked by means of the gates G G, which are supposed to be constructed on the principle of loose flash boards, whose ends slide in vertical grooves along guide posts. By means of these gates, which might be arranged in any other manner, the water surface of the canal above the weir is made to rise to about 1 foot above the water surface, just below the checkweir. One foot fall from upper water to lower water in the main canal is not necessary, but is desirable and should never be less than one-half foot. Through the gate H enough water is admitted into the receiving box I I to keep the same full to the crest of the overfall edge J J. This overfall edge may be made movable by closing the spaces between the posts on the side of the receiving box by means of loose boards, of which the upper one in each case is provided with a sharp edge, preferably of thin wrought iron.

From the receiving box water is admitted through a gate, K, susceptible of close adjustment (submerged orifice) to the measuring box L L, whence it flows over the weir W into the branch ditch. At a convenient point in the measuring box a graduated scale is securely fastened to the side of the box, on which the elevation of the water surface in the measuring box indicates at once the number of cubic feet per second which are passing over the weir.

The weir for use in this box may be constructed according to any approved pattern. It should have a sharp edge, and may have vertical sides or inclined sides to compensate for contraction. It can be made long or short, but should generally be about 2 feet shorter than the width of the box L L. The length of the crest of the weir should be adapted to the water quantity ordinarily required to be passed over it.

With this measuring box (or module) the requirements prescribed by Prof. L. G. Carpenter, of Colorado, and other eminent hydraulic experts can readily be fulfilled.

The quantity of water delivered by this measuring box in a given time is a definite quantity, and is measured with reasonable accuracy if proper attention has been paid to the conditions which should prevail and are prescribed by hydraulicians to secure correct weir measurement. The crest of the weir must be horizontal. Air must have free access under the sheet of falling water. Weir sides should be at least as far from the sides of the measuring box as the maximum depth of water intended to be delivered over the weir. Weir sides, when water quantity is to be determined by length of weir without corrections for contraction, should be inclined one-fourth horizontal to one vertical. The crest of the weir and the sides must have sharp edges, which should be in the same vertical plane.

The channel of approach, that is, the water way between bottom and sides of the measuring box, should be ample to reduce the velocity of approach to less than one-half foot per second, when the weir is taxed to its intended maximum capacity. The water must have a free outfall; that is, the water surface below the weir should be so much lower than the weir crest that its influence upon the shape of the surface of the overfalling sheet of water is not readily perceptible.

The measurement of water passing over the weir is perfectly reliable when, in addition to the above requirements, the following conditions prevail:

(1) When water flows over the weir crest with a depth of 0.25 to 2 feet.

(2) When the depth of water on the weir is less than one-fourth the length of the weir.

(3) When the height of the weir crest above the floor of the measuring box is at least twice the depth of water on the weir.

When these three conditions do not prevail, that is to say, when a very small quantity of water is delivered over a large weir, or when a weir is taxed beyond the maximum flow for which it was intended, then results are only approximate.

There are comparatively few cases where ample fall from main canal to the distributing canal is not available for the introduction of a measuring box, as above described, and in the main canals the necessary fall of one-half to 1 foot is always available, except occasionally in the case of main canals, which have been carefully constructed to grade lines. In these a backing up of water for one-half to 1 foot is always permissible, except when the canal is flowing at full capacity, and then water may be admitted direct from the main canal through the gate H into the measuring box. At such times water is plentiful, light fluctuations in the elevation of the water surface above the weir are least objectionable, and the canal water surface has greater stability at that stage than at any other.

In this measuring box an orifice under pressure may be substituted for the weir, but it will not be found satisfactory except where prejudice, as the result of long-established custom, prevails in favor of a delivery of water by "miner's inches."

Artesian Wells in San Joaquin Valley.

Fig. 1
Ground Plan of Artesian Well
and Reservoir

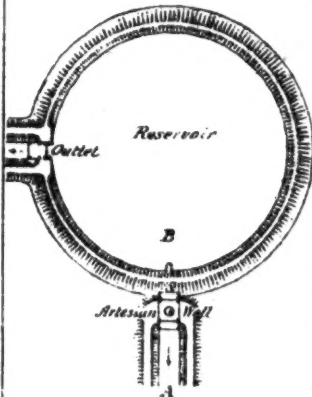


Fig. 2. Section AB

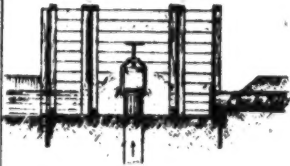


Fig. 9.

Cutler Salmon's Well
near Stockton.

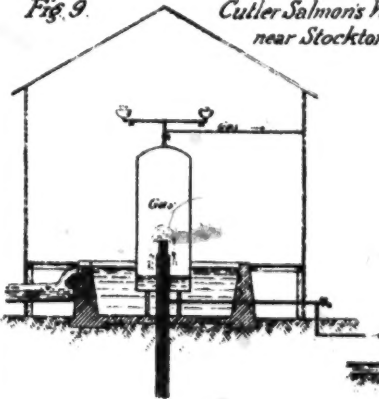


Fig. 8. Harris' Well at Hills Ferry.

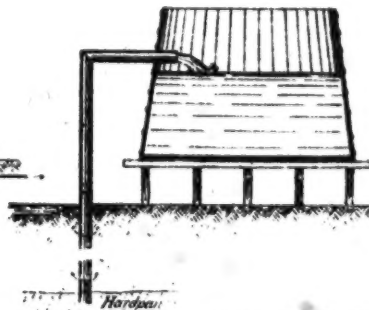


Fig. 3.
Raymond Well
Kern County

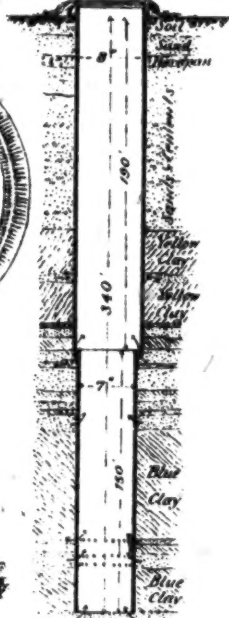


Fig. 4
Ordinary
Casing.



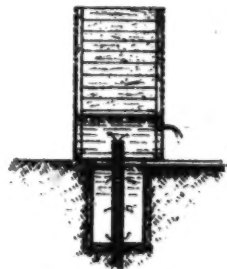
Fig. 5.
Screw-Joint
Casing.

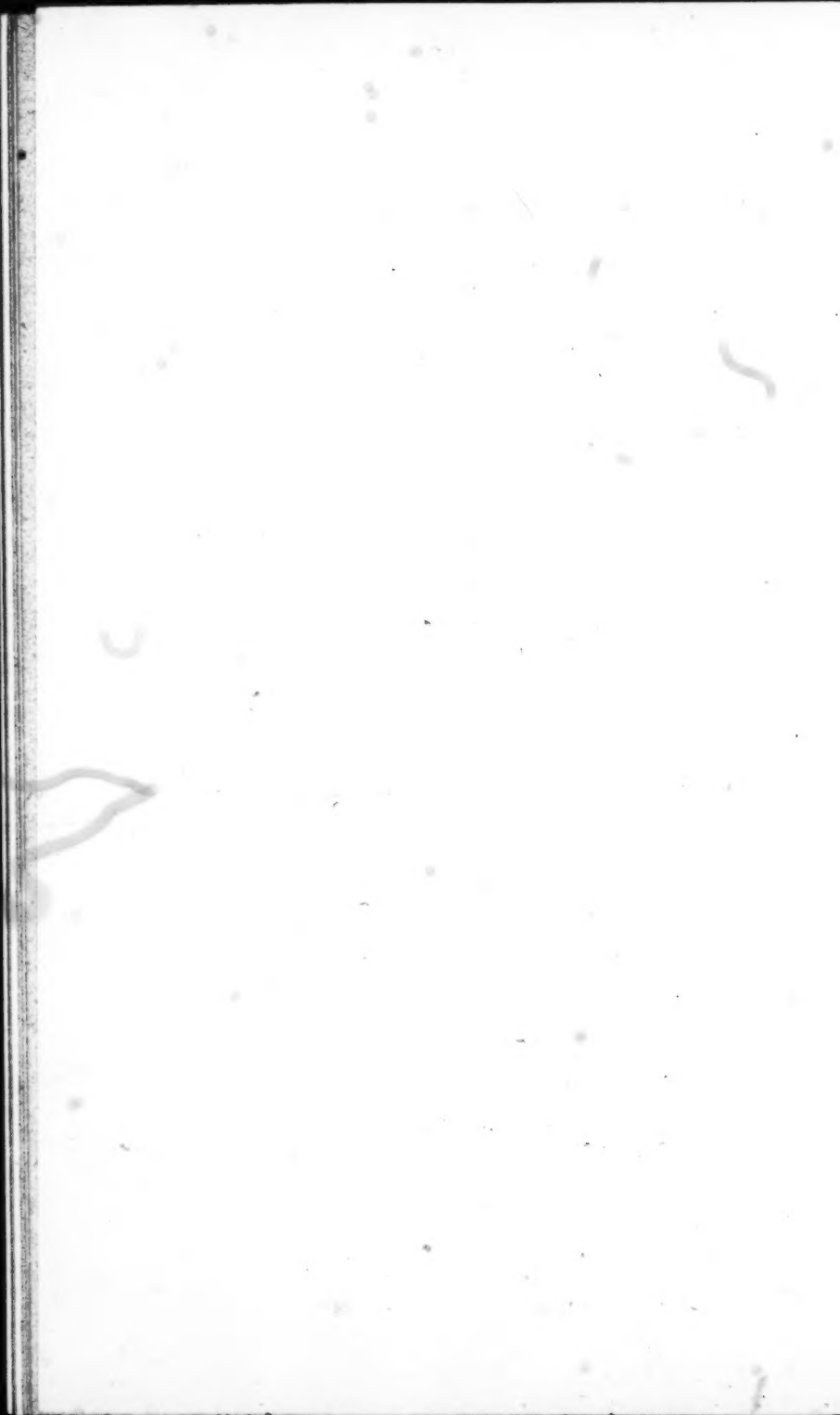


Fig. 6.



Fig. 7





Measuring Box

by
C. E. Grunsky.

Fig. 1 Section AB.

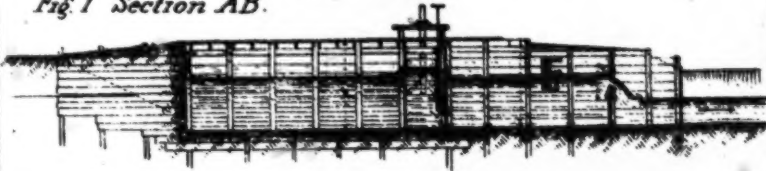


Fig. 2 Plan.

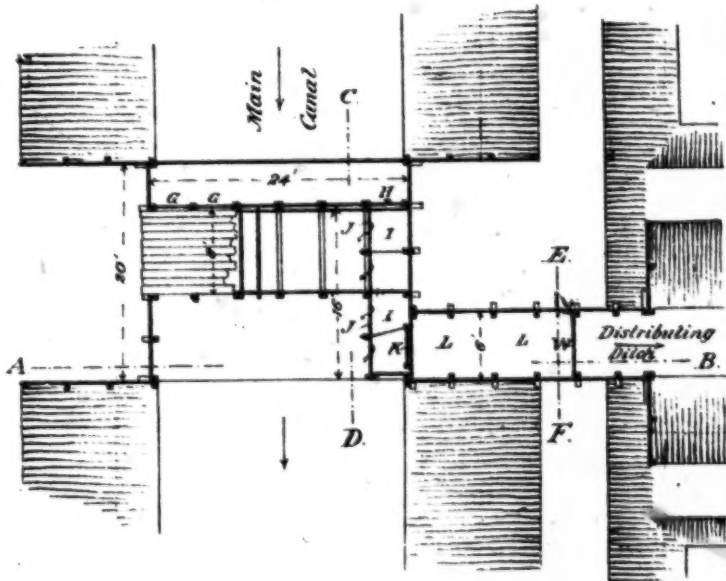


Fig. 3 Section CD.

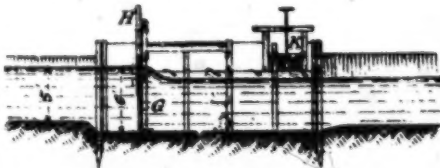
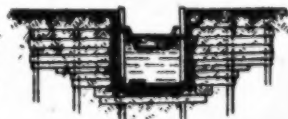


Fig. 4 Section EF.





CULTIVATION OF THE SOIL BY MEANS OF IRRIGATION IN SOME OF THE SOUTHERN STATES.

LOUISIANA.

Considerable discussion has been had in various associations over the value and necessity of irrigating the important sugar cane and other crops. Rice, one of the staples of Louisiana, is of course cultivated by means of irrigation, and it is the example it always offers that induces other planters to turn to this source of security when the heated term so seriously affects the welfare of their valuable crops. The idea underlying present debate is forcibly expressed by the Louisiana (New Orleans) Planter of October 10, 1891, as follows:

As we progress in our studies in the use of water for the forcing of plant life we shall doubtless find that we can aid or modify the influences of nature readily and effectively by irrigation. Our months of highest temperature, July and August, are of course those most conducive to active plant life, and the proper supply of water is an essential of such life.

As against the conclusion founded upon seemingly limited data, the year of 1889 stands out strongly. With an August rainfall in New Orleans of above the average, omitting the abnormal one of 1888, yet the crop was a short crop, and was caused by the evident drought that began early in that year and continued throughout the year. With a largely increased acreage the crop fell off some 20,000 tons, notwithstanding the record shows adequate rainfall, or an excess, in August and September.

We present these studies not claiming that any sound conclusions can be based thereon, but to create an interest in this line of inquiry, it seeming evident that our cane crop is now more dependent upon the supply of water for vegetation than upon that of temperature during the summer months, the necessary temperature being assured by the records, while the rainfall is the variable factor. To secure adequate moisture we shall probably have to call in the art of irrigation to supplement the deficiencies of nature.

Papers of value were prepared and read before the Audubon Agricultural Associations of Louisiana, during the year 1891, which present in so intelligent a form the reasons for an interest there in irrigation, that it is deemed proper to insert some extracts from them in this place. At the Audubon Association meeting held in June, 1891, one of the essayists read a paper in which the following points occur:

Nothing is better for pastures or for the hay crop than irrigation; but for melons, squash, cucumbers, cabbages, and other vegetables, where irrigation or submerging during the growing season may be extremely dangerous, nay, fatal, I have used the sprinkling can with great advantage. Small wells are dug in the ditches, say every one-fourth of an acre, in order to have the water supply close at hand. One small boy can easily keep ahead of two live men whose duty it is to immediately cover the moist ground by pulling dirt to the plants; by this means I have watered from morning to night with great benefit to the plants; but, on a large scale, I would advise a system of windmills supplied with sufficient cisterns or tanks properly elevated so that sprinkling carts could economically obtain the water; these carts could be so arranged that three or four rows could be sprinkled at one time, and if care be taken to cover up the moist dirt immediately by means of rotary hoes or other implements, watering can be continued with impunity during the hottest and driest parts of the day; for if this is not done the moisture obtained at so great an expense is soon absorbed by

the rays of the sun, and the ground becomes so hot that the tender roots of the plants become scalded.

Another plan that has been tried and given satisfaction is to fill small wells situated in the ditches at regular distances (say the ditches themselves could be filled with water obtained by means of a syphon or water pipe), then a portable steam pump drawn by two mules can water or sprinkle one-half an acre on each side of the ditch, and if care be taken to immediately cover up this moist ditch, acres upon acres could be sprinkled by means of such an apparatus in a day. In my opinion sprinkling is preferable to irrigation proper, for it imitates in a certain manner the rain, for there is no doubt of the fact that when water is aerified it becomes charged with more elements of fertility, and is better not only for the vegetable but also for the animal creation.

Another system that has many advocates is a system of irrigation and tile drains combined.

Such system of watering would prove of incalculable benefit to the truck farmer, for many vegetables are planted, grown, and are harvested in six to eight weeks' time; a drought of three or four weeks must necessarily diminish our production one-half, making our profits considerably small, and, as we farm for profit, it behooves us to lessen as much as possible the danger incidental to atmospheric changes.

Mr. Gus. V. Soniat read a paper of considerable value;* he presented concisely the leading facts in regard to the world-wide use of irrigation, and then states that—

Irrigation is an indispensable adjunct to cultivation in a dry climate and a sandy soil, where the ground water is far from the surface, for water is essential to vegetation; deep-rooted plants find their supply in the low strata of the earth, but for superficial feeders, unless the rainfall be plentiful and come at needed times, the plants soon shrivel, die, and then decay for want of this necessary element, and no wonder, for the majority of plants need moisture, heat, soluble soils, air, and light.

"Out of these five necessary elements, three," says Mr. Soniat, "have a preponderance of water." He continued, as follows:

Whenever the ground water falls to 13 or 16 per cent the majority of plants will suffer, unless the hydrostatic conditions of the air be exceedingly favorable. * * * Water then must be supplied in some manner, shape, or form, and a proper relative between the five necessary elements above-mentioned must be maintained. * * * The necessity, then, of ground water must be apparent, and to supply it we must by artificial means when natural ones fail. According to Storer, the rainfall is not sufficient to supply the evaporation caused by the sun; even here in Louisiana, with an annual rainfall of about 60 to 70 inches, how much of this water is utilized by the growing plants? I dare say a very small proportion, for we are in the greatest hurry to send it to the swamps as quickly as possible in our open ditches; and we call this drainage! Yes, a drain is upon our superficial soil, and it is a wonder to-day that the vegetable portion is not completely washed away.

The fact seems incredible, but I have seen dry land turned over by a two-mule plow immediately after a 3½ inch rainfall, thus showing conclusively the wanton waste of this fluid. Tile drains have partially remedied this evil, and have done wonders in augmenting thereby the vegetable power of Louisiana clay soils, rendering them nearly as porous and consequently as great retainers of humidity as our sandy loams. But how greatly could we increase this were we to utilize this vast amount of moisture and give it to the plants at different times; an acre of our land would be worth fully twice as much as an acre of northern lands; for if we multiply our average temperature by our annual rainfall (this is an old French rule), and make a comparison with theirs we find that we more than double their vegetative power. Our annual rainfall is about 60 or 70 inches, and our average temperature about 70° F., whilst in many States the rainfall varies from 40 to 50 inches and their average temperature 40° to 60° F.; yet, strange to say, some Northern and Western farmers are able to compete with us in certain vegetable productions. And why? Simply because either by artificial or natural means a better relation between heat and humidity is maintained during the growing season of the plants. * * * We irrigate and irrigate with a vengeance, not only our rice fields but often the cane fields of our neighbors, to their detriment and annoyance. But few cane farmers are aware of the fact that a rice planter is often a great benefit to the neighboring crop of cane for the following reasons:

(1) By filtration through the soil the necessary ground water is supplied to the canes.

* On the Possibilities of Irrigation in Louisiana, Audubon Association.

(2) The rainfall in any locality is greatly augmented by the rice planter, for "water will draw water," as the old saying goes, for the simple reason that hot vapors passing over a water surface, meeting relatively cool vapors constantly arising from the said surface, become condensed and fall in the form of rain, not only for the benefit of the rice field, but also for that of the whole neighborhood. The contrary is the reason why there is no rainfall in the desert, for the dry heat constantly arising repels and keeps in a vaporous state the moisture that may be floating in the atmosphere.

Irrigation, then, when properly understood, is a source of health and wealth, but when improperly used breeds pestilence and death, misery and all its concomitant evils; witness the evils occasioned yearly by badly-constructed pipes or flumes, etc. Our rice planters owe their wealth and success to the proper use of irrigation, for by this means the expenses have been considerably lessened and the yield greatly augmented over the dry culture, but constant care and attention are required for success; if, perchance, they irrigate at inopportune times and are unable to quickly drain their rice fields the stand of rice is endangered; or if they maintain too great a supply of water when the plant is young it can not tiller and becomes too slender to resist the storms of summer. Drainage and irrigation, then, must follow one another to insure success in all crops; in fact, the oftener we water and drain young plants the better. Our crops will be, for if we observe the root development of plants we will find that the roots are often double the length of stalks when the plants are young, but afterwards the stalks become twice the height of the roots. It stands, then, to reason that one watering or irrigation in time may be worth to the roots (hence to the plants) two or three later on. This is the reason why we must thoroughly prepare our soils before the planting of any crop and work the same in its early infancy in order that the young and tender roots may not be obstructed or impaired in the least, for if they are checked in the beginning of their career the plants become stunted and refuse to grow or develop as the farmer desires. Why, then, are the farmers in this section so backward in utilizing this great river that holds in solution yearly more tons for of fertilizers than the boasted guano beds of South America? Why, then, have the progressive cane planters not imitated the cane farmers of India, who irrigate regularly their canes?

Because success has not placed her stamp upon the ventures of those who have had the audacity to try this on our soils. May I be bold enough to point out the causes of their failure? Perhaps then a remedy may be found.

(1) Irrigation has been tried in the spring, when the river water is from 15 to 20 degrees colder than the soil, thereby injuring by such a sudden transition the tender cane roots.

(2) Because it has been tried in the summer in the heat of the day instead of night, thus scalding the roots.

(3) Because it has been tried to flood from the ditches by forcing the water to rise on the land, thereby expelling the air contained in the soil, stopping the drainage conduits and packing or puddling our clay lands.

(4) Because a drought in lower Louisiana rarely exceeds four or six weeks, or barely one-eighth of the growing time of cane, which is not enough to materially injure the growth if properly worked and highly fertilized; but when a drought lasts as it has lasted this year our cane crop can easily be reduced one-third or one-fourth. The only way of successfully irrigating cane or corn is to allow a certain amount of water to course down the water furrows late in the evening or during the night; for if we flood the entire plat of cane or corn, the sudden transition from excessive dryness to excessive moisture will certainly injure the roots that are then deep in the soil, and compel the plants to form new roots near the surface, and lose thereby valuable time to the detriment of its growth. When we flood the entire land the effect is as bad or worse than when a flooding rain comes. * * * The greatest drawback in cane culture is not generally the want of rain during the growing season, but to its absence during the months of October and November—the time of preserving our seed cane. We are then in such a hurry to prepare for the grinding season; we are in so great a dread of Jack Frost that from the fear of Scylla we fall into Charybdis; from the fear of losing a few top eyes we run a greater risk of losing all by dry rot; but some planters now prefer to wait for a light frost before windrowing, claiming that the canes are hardy, and are therefore better able to withstand the winter. But the reasons, I think, that can be given to the better preservation of such seed canes are:

First. The later we put our seed cane in windrows the less time it has to spoil; hence the better it keeps.

Second. Generally, after a few light frosts, we have a rain, for the reason that the vapors constantly arising from the Gulf of Mexico, meeting the cold currents of air that has given us these frosts, become condensed and thereby produce rain or enough moisture to preserve our seed cane. But generally we windrow in a drought and trust to luck; nine times out of ten luck is against us, when a little pluck or energy would save us; we are, as Tantalus, surrounded by water and we perish with thirst. We are encircled by plenty, and we die of want. What a shame for man's intelli-

gence, and what a shame must I have to acknowledge that I have suffered from the same cause when the remedy is so simple—irrigation. Two days' pumping with a good pump could easily moisten 100 acres of windrow or fall plant, at a nominal cost per acre, and forever banish this evil. We may suffer from wet rot, if not properly drained, but from dry rot, never.

Irrigation has been used with the greatest advantage in the planting of corn, peas, sweet potatoes, cabbage, etc. In a drought the rule to be followed is:

First, irrigate thoroughly; then drain. As soon as the ground has been dried sufficiently, planting can be done with dispatch, and failure is impossible. To prevent rust in oats I know nothing superior to irrigation during a dry spell.

At a meeting of the same association June 20, 1891, Mr. J. Y. Gilmore read a paper in which occurs the following suggestions:

In Louisiana the possibilities of irrigation are great; no doubt far beyond the comprehension of the most sanguine of us. While we have an annual rainfall of more than double the average throughout the United States, yet we are subject to the most severe drought, especially in spring time, when crops most need moisture. Hence in the near future irrigation will become common here. Along our water courses in alluvial Louisiana the lands are comparatively level, with a gradual slope from the streams. Hence, with a vast and inexhaustible water supply to draw from, and but little labor requisite to conduct it wherever we choose, in a short time every crop will be thus aided, for science has shown us that it is by liquid absorption that all plants take nourishment. It is no exaggeration to say that when our planters have perfect control (as they may) of both drainage and irrigation, the productiveness of our soil will be doubled. Thus a greater diversity of crops will be the result, for it has been proven that when conditions of the soil can be controlled vegetable culture is more profitable in Louisiana than any where else, because of climatic advantages.

Orange culture will be wonderfully stimulated by proper irrigation, for the losses from drought on newly planted groves are far greater than from cold. Then, too, there is no doubt that when severe colds are expected a proper water treatment will save many trees, which otherwise would be severely hurt by ice.

Drainage and irrigation are twin sisters, and without a perfect system of drainage irrigation is not practicable. Hence, subirrigation promises to become the popular method, for when the ground is properly tilled it gives perfect drainage, and when necessary (not so frequently, however, as on untiled ground), the water can be forced through the pipes, whose outlets being stopped will cause the water to rise to any height desirable, as was done recently so successfully by Dr. Stubbs at this station. Thus cultivation can be continuous, which would not be the case with surface irrigation. However, in subirrigation great care will have to be taken not to allow the water to stand too long in the soil, which would exclude the air as well as tend to fill the tile with sediment, but it should be drawn immediately after reaching the height desired, when the air will follow the receding water and leave the land in a highly porous condition, and at the same time avoid the baking of the surface, as when irrigated from above. However, Mr. James D. Houston, on his Ben Hur plantation, in the parish of East Baton Rouge, has this season irrigated his cane most successfully by the open ditch system.

When we consider that nature has given us such a bounteous store of water to be had simply by asking, it is a shame that any crop in our alluvial soils should suffer from droughts. Those who urge the objection that our waters are too cold are either unaware or unmindful that in Colorado, New Mexico, and elsewhere in the West, where all crops are made by irrigation, the waters are most of icy coldness, being from the melting snows of the mountains, and so cold that no fish except the mountain trout can live therein. Then, too, when it is remembered that these expensive canals are constructed to carry water along ditches, it should make us more highly appreciative of nature's kindness here and determine us at an early day to bring our land to the highest state of culture by a proper system of irrigation and drainage.

Dr. W. C. Stubbs, of Audubon Park and New Orleans, read before the Sugar Planters' Association of Louisiana a valuable paper on the need of water management and distribution for the security of the sugar-cane crop, which deserves to be reproduced in full.* Those portions only which bear directly on the cultivation of Louisiana staples by means of irrigation are, however, presented. Dr. Stubbs opens his important paper by asking:

Shall we irrigate in South Louisiana, a country almost submerged beneath water and which is known to have a very heavy rainfall?

* "Sugar Cane Irrigation," Louisiana Planter and Sugar Manufacturer, New Orleans, October 17, 1891.

He continued interrogatively at some length and then said:

The sugar planter . . . is particularly interested in every obstacle to maximum production. . . . He has realized that a full crop is rarely obtained oftener than once in twenty years, and that of the failures fully 80 per cent are assignable directly to drought.

The questions thus asked, Dr. Stubbs answers himself in the statement that "irrigation eliminates the great element of chance from our farming operations, and good drainage makes the planter nearly independent of the freaks and idiosyncrasies of the weather, is the concurrent verdict of those who practice this art." The doctor proceeded to give a succinct account of irrigation as practiced in other times as well as in our own generation, and then continues:

The short history given will show, first, that irrigation is not new and untried; second, that its beneficial results are so apparent to those who have practiced it that immense sums have been invested in permanent works; and, third, that irrigated districts yield the largest productions with the greatest profits. Just here permit a digression. The time was when the country east of the Mississippi, with its large annual rainfall, heavily wooded forests, and rich sugar soils, reveled in the conceit that it alone was the agricultural portion of the United States, and that their products would always be in demand in the less favored claims of the extreme west, where only mining and stock-raising were possible. But our forests have been felled, our rainfall decreased, and painfully irregular in its distributions. Our soils have been denuded of their virgin mold, and are no longer capable of enduring protracted droughts, consequently our crops are growing shorter, and agriculture is no longer the pleasant and profitable profession as of yore. While this gradual decline of yield has been going on in the East, a wonderful development of agriculture is occurring in the West. Science and experience have taught that deserts with favorable climatic condition may become highly productive and valuable by the application of water through artificial means. . . . What will be the result of this immense agricultural development, with certain crops yearly?

I was informed this summer by a prominent United States engineer, familiar with the country, that there were yet 125,000,000 acres in this country susceptible of being irrigated, and that each 25 acres irrigated were more productive of profit than 125 acres in the East, with the uncertain seasons. He further stated that every 25 acres would then support five souls. With these facts before us, it requires no prophet's vision to see the future wealth and grandeur of this now arid region.

And now let us discuss the subject from a home standpoint. It has been found that our maximum crops of sugar cane are produced in those years when the rainfall was well distributed throughout the season. From accurately kept meteorological records we learn that maximum crops of sugar cane are made in Louisiana after a mild and dry winter, succeeded by a spring with moderate rains, well distributed, in turn supplanted by abundant showers at close intervals during June, July, and August, winding up with decreasing rainfall in September, with the remainder of the fall clear and dry. Last year's, the largest crop on record since the war, was made with the following rainfall: January, 1 inch; February, 3.10 inches; March, 1.98 inches; April, 3.27; May, 10.71; June, 4.15; July, 7.30; August, 75; September, 4.56; October, 4.41; November, 0.87, December, 3.55, or a total of 52.65 inches, an amount nearly 8 inches below the average of five years, but well distributed for a cane crop, as will appear by aggregating into seasons as follows: Spring months, 15.96 inches; summer, 19.20; fall, 9.87; winter of this year, 7.65; winter, preceding crop, 4.53. The average for five years of the records kept at the station is nearly 59.09 inches, distributed as follows: spring, 16.59; summer, 19.06; fall, 8.19; winter, 12.46. The winter and spring rainfalls of last year were below the average, while the summer and fall were normal in quantity, but better distributed. Dry winters and moderately dry springs are conducive to subsequent large crops for two reasons: 1. The soil is put in excellent condition both as to preparation, planting, and early cultivation, and the motto a crop well planted is half made is an assertion based upon such experience and should be well remembered. 2. The above conditions, with a dry winter in this climate, are favorable to both physical and chemical amelioration of the soil. The former is apparent in its pulverization, permitting a subsequent good cultivation, and the second in the increased nitrification which takes place rapidly in dry soils during our winters. Favorable winter and spring conditions, with hot weather extending through the summer, are then needed for maximum crops.

The first condition in the growth of cane is drainage; that secured, the next is water, water at regular intervals, so that a maximum growth of cane may continue without interruption up to grinding. Unfortunately but few cane countries are vouchsafed these conditions by nature, and hence maximum crops of cane are rarely

made. In upper India irrigation is necessary and universally practiced. On the Rio Grande, in Texas, are sugar estates which depend almost entirely on irrigation for their supply of water. In the East Indies, Straits Settlements, and Java, so far as I am informed, the cane is grown only by moisture supplied by rain. In Singapore fine seasonable showers usually occur every fourth or fifth day, and splendid crops as a rule are raised, yet even in this favorable spot spells of dry weather do occur with great damage to the crop. Malacca, like Louisiana, has her periods of frequent showers and extensive droughts. In the West Indies long periods of dry weather are frequently reported with great injury to the crop. And yet few sugar planters anywhere appear to recognize irrigation as the great safeguard.

I may be permitted here to utter a belief that in the coming future every sugar plantation, wherever situated, will be provided with irrigation appliances and used whenever the crop is in need of water. This water can be supplied from rivers, from artesian wells, or caught and inclosed in immense reservoirs from winter rains, etc. Demonstrate the money value of irrigation and I believe human ingenuity can devise the means of supplying the water. Water is needed for the solution of the chemical ingredients in the soil, for the translocation of these substances from cell to cell in the plants, for the circulation of sap, etc. In fact irrigation is largely a chemical question, since water is the most essential ingredient entering into the growth and composition of the plants. Suppress it in part and the plant wilts and growth ceases wholly and the plant dies. With an abundance of water heavy manuring may be practiced with success, while in times of drought the smallest applications are without visible effect. Rainy years upon light soils always bring forth tolerable crops; hence the inference that irrigation on poor soils would always insure fair yields. Water is the vehicle for carrying food from the soil to the plant and produces the circulation of substances within the plant and causes the chemical processes and reactions which occur therein. It is also the very life of the plant. With abundant moisture, plants can use over and over again a given store of ash ingredients, and thus permit of an economy in these costly substances. The amount of water needed by plants is enormous; 75 per cent of our cane crop is water and 25 solids. This amount is nearly constant, and shows it must be essential for the physiological processes which occur within the plant. The contents of the cell must be kept moist. The protoplasm of each active cell must retain its glutinous semiliquid conditions in order that its functions may be properly performed. Decrease the moisture and you increase the consistency of the protoplasm, and with it, vital activity of the plant. A plant must be properly charged with moisture in order to grow freely. If not so charged, the first evidence given to us is by its wilting. By the osmotic pumping action of the roots, water is taken into the plants from the soils and rapidly evaporated through the stomata of the leaves. This evaporation is sometimes so great that a few hours of hot, dry weather would completely desiccate the plant, were not a continuous supply furnished by the soil. When the soil can not supply moisture as fast as evaporated the plant wilts. Numerous experiments have shown that this wilting occurs when the moisture of ordinary soils at 80° F. is reduced 10 or 15 per cent. This wilting does not betray the first suffering of the plant, but rather the beginning of decadence. Experiments have also shown that for crops like sugar cane, there is evaporated during growth, at least 300 pounds of water for every pound of dry matter contained in the cane. Our cane and tops contain about 25 per cent of water and 25 per cent of solid matter. On a crop of 40 tons of cane per acre there would be fully 12 tons of leaves and tops, making 52 tons of product. Of this 52 tons there would be 13 tons of dry matter. If each ton of dry matter utilized 300 tons of water, the crop during growth would have consumed 3,600 tons of water. One inch rainfall gives 27,154 United States gallons, or 113 tons per acre.

Our annual rainfall is about 60 inches, or about 6,780 tons per acre, nearly twice as much as would be needed to grow this crop provided it fell during growing season, and that none of it flowed off the surface through the quarter drains. But what are the facts? A large quantity of what falls goes off to the swamps, certainly 20 per cent, and during the spring and summer months, the season of growth, the average rainfall is about 35 inches, or a little over 3,900 tons, enough, if it were distributed, and no loss through quarter drains, to supply the above crop. But our rains are not well distributed, nor do they fall in such gentle showers as to permit total absorption by the soil. Hence the water to secure this large crop must be obtained from the winter supply in the soil and irrigation. * * * Our experiments this year show that the water delivered through a 6-inch pipe would easily irrigate 20 to 25 acres in twenty-four hours. Another benefit of irrigation with Mississippi water is fixation of matter held in solution and suspension, and its subsequent utilization by the plant.

This fact, first noticed by the French chemist, Maliguti, has been since fully established, and is expressed by practical men when they speak of water running off their plats "as used up." The double silicates and humus of the soil have the power of withdrawing from the spring and river water, potash, ammonia, magnesia, and

phosphoric acid and to a less extent of soda and lime. The excess of oxygen in the air of river waters also quickly unites with the oxidizable matters and is consumed. According to Humphrey and Abbott, the sedimentary matter carried by the Mississippi River is one part in weight to every 1,500 pounds water, or 1.4 pounds per ton. This matter is almost entirely deposited on the soil during irrigation. Besides this sediment, a small amount of valuable soil are held in solution, some of which are absorbed by the soil, and in the large amount of water used for irrigation these manurial additions have no small influence on the growing crop.

Do we need irrigation on our cane crops, and if so how can we best supply it? This is the chief question to-night. Our climatic conditions do not give us equable seasons. The first is easily answered in the affirmative. Droughts and excessive rainfall follow each other without regard to the season. Seedtime, cultivation, time, growing time, and harvest are all subject to these variable conditions, frequently causing immense differences in the profit account of the farmers. How much seed has been lost in dry rot, when a slight irrigation of the soil would have prevented it! How much seed has been planted and covered in dry, cloddy soils with little or no prospects of full germination because the planters could not wait for a rain! How often have we rolled with the plow and cultivator the obdurate clods to and from the young and tender cane of spring in our honest but fruitless efforts to pulverize them, when a mere saturation of them with river water would have caused their disintegration! If we reduce our crops to a money value, and estimate that of last year at 100, then our average annual losses from drought are fully 20 to 25 per cent. To grow maximum crops our plants must be pushed from the germ to the sugarhouse. This can only be accomplished by a full supply of plant food, good cultivation, abundant sunshine, and sufficient moisture. The amount of moisture needed during summer by the cane crop is enormous, and any deficiency of at least 1 inch rainfall per week during the growing season, is believed to be fatal to maximum growth. Less than this amount of water falling, the moisture should be supplied by irrigation. From a close study of the books kept at the sugar experiment station, it is believed that irrigation could have been successfully practiced at least fourteen times in the five years ending January 1, 1891, and four times this year have we irrigated with success, making eighteen times in six years, an average of three times per year. Having established the benefits of irrigation, the question is how and where shall we obtain our water? To one who has recently witnessed the enormous labor, time and capital necessary to secure water upon our lands far removed from rivers, the question affords an easy and ready reply, viz: From the Great Father of Waters and its outlying bayous flowing past our doors nearly every sugar planter can draw all the water needed. A boiler and pump or an elevator of some kind is needed to lift the water over the levee. If siphons be used the former would only be required while the river would be below its banks. Some may say that we can not irrigate a thousand acres of cane. I may reply that they have already accomplished far more difficult and less profitable enterprises.

The writer has seen successfully irrigated fields of far greater inequality of surface than most of the cane fields of Louisiana. Lay off carefully on each place the line or lines of greatest elevation, running from the levee to the rear, and constructing ditches along these lines for the conduct of water through the plantation, and into these ditches pump the water. From these ditches have quarter drains running into each plat, and use these as laterals and distributaries, filling plat after plat, using wooden troughs to cross the drainage ditches. I verily believe that the plan can be easily and cheaply executed on every plantation, and the saving in one crop will pay for the entire outfit.

We have already published an account of our irrigation experiments at Audubon Park. They were begun too late, and yet the results are astonishing. Our drought began on March 16, and irrigation was not begun until May 4. In the meanwhile our canes had suffered, and the effect of this drought is apparent I believe to-day in the decreased diameter of the canes over last year. The height is fully as great and the number to the running foot greater than last year; but nowhere among either home or foreign canes have we the size of the stalk, which defect we attribute to early drought stunting the size of the cane. Irrigation was subsequently applied as follows: May 18 and 19, June 3 and 4, July 1 (on one plat only a shower making further irrigation unnecessary), and September 7 only on spring plants. There are five tile-drained plats on the station. All the tiles are connected with the common main. In the beginning of our experiments it was determined to leave two of these plats unirrigated, and our plans were so adopted. In irrigating the three plats it was found that the tiles were discharging the water nearly as fast as we were pumping it in, and it was necessary to hold it on the plat to make it reach several spots that were higher than the rest. The main discharge was, therefore, closed, and in a few hours all five of the plats were wet—three from surface irrigation and two from the raising of the water through the tiles or subirrigation. This first experiment was repeated, each subsequent irrigation with similar results.

During August another drought prevailed. I was absent at the time, but daily expected, and on my coming everything was ready for irrigation, so, on September 7, when the canes were polarizing 8 to 10 per cent sucrose, we gave two plats another irrigation and only stopped from irrigating the entire crop by excellent showers which have prevailed ever since. Now, for the results—cane, corn, cotton, and cowpeas have been irrigated during the year. Six acres of corn were forced by irrigation into early roasting ears and sold to the Italians. The amount realized from this source was nearly \$500. Enough was left undisturbed to show that the yield was over 100 bushels per acre, while another patch irrigated gave a yield of about 25 bushels per acre. The other crops have not been gathered. They are subject to inspection by any one interested in irrigation. The cane crop, it is believed, will be as large as the very large one harvested last year, and is in strange contrast with a piece of spring plant, which never received any irrigation whatever.

In closing, permit me to say, that from a close study of cane-growing for six years, I am convinced that water as an element enters as the predominant factor into the problem of successful sugar-planting in this State. How to get rid of an excess is the great question of drainage, already studied and developed. How to supply the deficiency is the present and future agricultural problem, and I verily believe that this intelligent body will furnish as satisfactory a solution of this momentous question as it has done in the past with the many serious issues which have engaged its attention.

In the discussion that followed Dr. Stubbs's paper, the doctor said that the necessary ditches could be made for from \$2 to \$5 per acre. The cross laterals ought to be small. He added:

We found in our experiments at Audubon Park that, starting the water about half an acre from the fence, and running down parallel with the circular road, a stream that I should say was about 1 foot wide and about 6 inches deep, we irrigate five plats, running three or four streams in six to twelve hours. Now, as to the streams, the number, of course, depends entirely on the size of fields to be irrigated.

Ours is a common 6-inch pipe, having a drainage trough. That 6-inch pipe can easily irrigate 20 to 25 acres per day. From the time we commenced, say we would get to work about 9 a. m. and close somewhere between 9 and 12 p. m., we would irrigate from 12 to 25 acres in a day. Ours is a force pump, and we could irrigate from 20 to 25 acres in one day. The main pipe is a 6-inch one, as is also that leading off from the discharge. The latter flows into the trough that irrigates the field. We use an old pump, and if it had new pistons, it could drive with more force and lift more water. I do not think there will be any trouble in getting water over our lands if there is another drought of seven or eight weeks. I am satisfied that the results of the park would have been far more satisfactory had we commenced irrigating sooner. We commenced May 4, and I think had we started about the 20th or 25th of March our cane would have been fully 10 per cent better. Our canes should be wet at least once a week from the time they germinate until ready for the sugar house. Where the soil was subirrigated the soil was not disturbed at all. I could hardly tell that any water had been on it except a little flood that I saw rising; while on the other plats that were surface irrigated it left a hard surface on the top; so I prefer subirrigation. Now, we permit the water on the surface first to filter through the soil to the pipes, then rise back through the tiles onto the soil. * * * I will state if the water was kept in the tiles perfectly still some of that deposit would be deposited therein; how far it would be washed out by subsequent rains I can not answer. I never had any experience. I hardly think it would. Of course, we send into the diffusion battery water perfectly muddy and dirty; when it comes out it is as clear as it can possibly be. It is filtered through the chips and is perfectly clear.

Mr. Soniat also said during the discussion:

I have tried to irrigate cane as you state on the rice plan, but the trouble was it stayed too long on the land. Dr. Stubbs is better favored than I was. His land is new, being land that has laid a good many years idle, consequently porous, and he may have risked putting water on the land two days without any injury whatever; but I have tried it on old lands and always found injury done to the cane thereby. If water remained in certain places I found in a few days thereafter the cane would turn yellow. I have always found that if water remained too long on young cane in the springtime the cane would be injured. I think by leaving the water start at one end to flow down the furrows, and not to permit it to remain longer than a day or two no injury will be done. On the contrary the cane will be much benefited, provided the day thereafter, as soon as the land becomes dry, the crust is broken, which permits the air to penetrate the soil. I found that in this way a great deal of good was accomplished. I tried it only one year on sugar cane, but have used it mainly on truck farming. We take water cans and sprinkle the plants, but you could never

de that with cane; truck farming is entirely different. The hills are far apart. One man can water an acre a day and it is very cheap. But watering sugar cane with watering pots is a very different thing. I think the only practicable way is, as Prof. Stubbs has done, to flood; but as soon as possible thereafter the soil should be drained, and under no circumstances allow the water to remain on the land any more than one day, and immediately thereafter plow the land—the same as we are compelled to do after a rain flood.

If a planter leaves his crop after a rain flood from three to six days, as soon as it dries the soil will crack and the sun will penetrate the roots, and in this way much injury is done. If all the cracks are stopped up, of course the sun will not go through the ground. The roots then become exposed to the sun, and in this way the roots are struck, destroying their vitality, and the leaves then turn yellow. I think there is a great deal more injury done in this way by the sun than by floods. Prof. Stubbs and myself have been studying this for years, and I think anyone can follow his footsteps with safety.

"Sugar Cane Irrigation" is the title of a paper read by Mr. Adolph Thiel before the meeting of the Louisiana Sugar Planters' Association, October 8, 1891, extracts from which are here given:

* * * As the success of irrigating sugar lands has been demonstrated beyond a doubt, I think it pertinent to consider the most advantageous mode of irrigation, in conjunction with the subject for discussion. It will be remembered, perhaps, that I have advocated for more than two years the use of drain tile for irrigation purposes, basing my theory upon the fact that the water, if forced into the tile, would distribute itself through the soil in the same pores and channels that it finds its way to the tile in wet weather. Dr. Stubbs's experiment in irrigating two tile-drained plats proved the correctness of my theory beyond a doubt. Although an account of the experiment has appeared, for a better understanding I will repeat the report in brief, which is in substance that plats 3, 4, 5, 6, and 7 had been tile-drained in early spring. In order to determine the difference of results on tile-drained land irrigated and tile-drained land not irrigated, plats 4 and 6 were not irrigated. But as the water would not run beyond the first line of tile on each plat it was found upon investigation that the water escaped through the outlet tile, which was then stopped up to prevent any more waste of water, with the result, however, that the water was distributed throughout the tile-drained plats (they being connected with each other through the main tile), and all of the tile-drained land was equally irrigated and benefited, as I could see no difference in the looks of the cane when I saw it.

It is claimed by opponents of subirrigation that in this experiment the water found its way to the surface simply because the dirt over the tile had not become settled or puddled at the time, and that the water rose to the surface in that place only. I am prepared to meet that assertion with a statement from Dr. Stubbs to the effect that moisture appeared on the surface of plat 7, which is from 6 to 18 inches higher than plat 6, the highest place where water was applied. The appearance of moisture on the surface of plat 7 was due solely to capillary action.

The entire practicability of subirrigation being demonstrated, it remains only to point the advantages of such a system over another. * * * By surface irrigation considerable time elapses before the soil can be stirred after the water has been applied. In California and other places where crops are raised by irrigation exclusively, the ground is stirred with the plow or cultivator as soon as possible, and no doubt the rule should hold good in irrigation of sugar cane as long as it is not laid by or not tall enough to shade the ground sufficiently to prevent the cracking or baking of surface soil. But as even the Mississippi bottom lands are rarely smooth enough for the equal distribution of water over the surface, with surface irrigation more water will accumulate in some places, delay the stirring of the ground, and cause loss of moisture by evaporation. On the other hand, with subirrigation, stirring of the soil may be carried on simultaneously, thereby preventing any waste of moisture.

In order to distribute the water equally by surface irrigation numerous dams and channels are necessary, demanding constant attendance. These dams and channels can only be temporary, as they would interfere with the surface drainage in case of wet weather. By surface drainage the channels are permanently established, as a uniform continuous grade is essential to the success of a tile drain. By the addition of the few valves, any system of underdrainage can be made to serve the double purpose of drainage and irrigation.

On the question of "Artesian wells for irrigation," Mr. R. S. Rickey, manager of a "hydraulic wells" company at New Orleans, writes to the Planter of October 17, as follows:

In experimenting with irrigation during the spring and early summer drought, Mr. Benjamin Bourgeois, manager of Mr. Leon Godchaux's Elmo Hall plantation, irriga-

ted a piece of black stiff cane land which seemed to be dying, and it is now as good as any plant cane he has. Dranzan Himel, of Assumption Parish, says that by irrigation during the same period they saved one-half of their crop and made the only good corn crop.

In speaking of wells and their capacity, we put down two 6-inch wells on Elmo Hall for Mr. Godchaux this year, and measured their capacity by pumping the water into large tanks. In this way we ascertained that the two wells gave 765,000 gallons of water in twenty-four hours, with Bayou Lafourche at its lowest stage. A 6-inch well just completed on Messrs. Whitehead & Kent's Abby plantation, Lafourche, gave at the rate of 465,000 gallons of water in twenty-four hours, while a 4-inch artesian well at the Calcasieu Sugar Company gave at the rate of 500,000 gallons in twenty-four hours. We are now negotiating to put down an artesian well for the town of Lake Charles.

The same parties have put down, according to Mr. Rickey, in all 102 "hydraulic" wells in the sugar district, 45 of them being made during the past year.

A "dahl" is a flume built in the river levee for the conveyance of water to the rice fields. Their situation, unless properly gained, tends to weaken the levees. Hence the legislature has provided for rigid requirements. During the year 1890, however, such a flume weakened the Ames levee near New Orleans, and caused a serious crevasse. It is asserted that the old system of construction was more efficient than the new. It is thus described by a New Orleans writer, Mr. W. W. Pugh:

The old fashioned "dahl" is made of sound 3 inch cypress plank of one length. This is supported by three brick walls, built so as to extend some distance above the top of the woodwork, in order to interfere with the work of crawfish and muskrats, which would otherwise follow along the line of woodwork and give rise to leaks, and finally to the blowing out of the whole woodwork of the "dahl" and leave a large opening in the levee through which the water would rush with a mighty force. In addition to the walls, but as a support to the dahl, good lime and plenty of it is used to form a strong front to the brick between the brick walls, which in a few days becomes hard, and when the dahl is taken up for renewal, or any other cause, requires to be removed with a pickax.

The State law demands that the dahl should be made of iron instead of good cypress lumber; it does not require the support of brick walls or the surrounding of the iron pipes by strong mortar or grout. There is no obstacle then to crawfish and muskrats, and leaks at the joints of the pipes or along it will necessarily in a short time end in its being blown out. Flumes constructed of good 3-inch red cypress plank will hold good for ten years or more. They are built of one length, have no joints to leak, and if properly constructed and laid down are just as reliable as the inch pipes as long as they last. These flumes should be replaced every five years. Iron pipes soon become honeycombed with rust.

The season of 1891 was marked in Louisiana by long drouth, beginning in some portions of the State as early as the latter part of March. This condition created a great interest in irrigation. Mr. S. Mills, of Oakley Plant, Albermarle post office, wrote the Planter under date of May 26 in relation to his experience as follows:

After five weeks of irrigation on a place whose peculiar topography enables me to irrigate naturally with swamp water over three-quarters of it, I still find myself very much in the dark, and with far less success than I at first anticipated. I see before me fall cane, and some succession cane, with water in ditches up to the water drains for the past four weeks, parching up, and not a few stalks dying, the ditch-bank rows, right along the water's edge, suffering even more than the interior rows. The middles show considerable moisture to the plow, and in some places, the water having slightly entered the water drains, a profuse growth of "milkweed" shows along the edges, but the cane still refuses to be comforted, and like the paradoxical shipwreck, still cries for water. I have also in some portions of the field, pursued another course of irrigation. I dammed up my ditches at the first water drain of the upper end of the cuts to be watered, closed the outlets of the water drains (excepting the first one alluded to), leaving the ditches open through the cuts, and allowed the water to rise sufficiently to overflow the first water drain and follow the dip of the land.

By the first system the water rises, or is supposed to rise by capillary attraction up

to the cane; by the second system it percolates through the soil downward just as a rainfall would and eventually reaches the ditches. Under the first system I can see no perceptible benefit to the cane; under the latter considerable. I take it that the second system is as near the mechanical action of rain as we can obtain it on any extended scale. I am not set or at all settled in the matter, but if the latter view should prove generally correct, a small pumping outfit on wheels, capable of being easily conveyed and turned about on the turn rows, with a capacity of irrigating 20 or 25 acres a day, might be got up for about \$1,500, and would be a valuable adjunct for other purposes on a plantation.

By taking cut after cut, closing the outlets of the water drains and pumping water on the highest point from running water in the ditches, guided only by such small locks or dams as might be needed to have water accessible to the pump, I think such a course and outlay this season would have reclaimed an immense amount of plant cane and many times over repaid the investment.

Siphons in connection with pumps are coming into use in Louisiana for the conveyance of water over levees, when needed for irrigating the can and rice fields. It is considered by many a mode of conveyance cheaper than a flume, which latter method is more largely used. Mr. Sherland, a planter, says that—

In order to insure the full performance of a siphon it should be made of iron heavy enough to be calked, the same as a steam boiler. This idea of making a siphon of thin tank iron and depending upon the rivets and lead to insure a tight job is a fallacy. While new, it may work a short time, but the iron being in the sun will expand and contract in the different temperatures that it is subject to, will soon loosen at the joints, and a planter will condemn a siphon and tap the levee to obtain his supply of water, and by so doing he will soon have a supply of water, and his plantation can only be found by the sailor's lead.

Again, there should be in the lower end of the siphon some means of holding the water until the pump has made a perfect vacuum. Then, when the lower end of the long leg is opened, there will be a solid volume of water flowing until air accumulates in sufficient quantities to cause a cessation of the flow.

All water that is exposed to the atmosphere contains a certain amount of air, and that air will seek the top of the water whenever the conditions are favorable. Hence there is a tendency to lodge in the highest points of the siphon until sufficient has accumulated to cause the water to cease to flow. Siphons should not be condemned until all laws governing the flow of liquids have been complied with. With regard to the presence of air in the siphon preventing its proper working, Mr. Soniat, president of the Audubon Association, says, in a published communication, that the remedy for the hindering accumulation is to have an "air vessel on top of the siphon. The horizontal portion of the siphon lying on the top of the levee should be slightly arched; then, by placing the pump at the top of the air vessel, it will fill the whole siphon and air-vessel with water. A glass water gauge on the side of the air vessel will show when it is full and will insure a steady flow of the full capacity of the siphon. This is an experiment." He adds, that "when once understood, a siphon is no more trouble than a flume; is cheaper; requires no cutting of the levee, and, if required, can be moved from one place to another with very little work. The main point of having a properly constructed siphon is to place it so that both ends will be covered with water, and to have in front a small reservoir to allow time to close the siphon in case the pump stops."

The irrigation experiments of the Sugar Experimental Station (Audubon Park), Louisiana, during the planting season of 1891, are of importance to cane planters. In describing these experiments, it is said:

Our climatic conditions do not vouchsafe to us equable seasons; droughts and excessive rainfalls follow each other without regard to the time of the year, seed time, growing time, and harvest, and all subject to these variable conditions, frequently causing large differences in the profit accounts of the farmers. Tile drains are believed to be a remedy to heavy rainfalls, and to a large degree will mitigate the severities of a drought. But, however well laid, they can not supply the necessary water for growing crops in a protracted drought.

It seems essential for the production of a maximum crop of cane in this climate that the plant should be pushed into growth as early as possible in the spring, and maintained in a healthy, vigorous, growing condition until fall. This can be done only with showery at short intervals, extending through the spring and summer months. Unfortunately, this rarely occurs. Experience has demonstrated that whenever the rainfall for a month during the growing season is less than

2½ inches, the plant fails to accomplish its maximum growth, and may with profit be assisted with irrigation.

It is believed that the Father of Waters, so often a terror to our planters, could sometimes be used with considerable profit in supplying our crops in the growing season with water, when the rainfall is less than 2½ inches per month. To find out how often this accessory to our wealth could have been profitably used in the last five years, a special study of the carefully kept meteorological record of the Sugar Experiment Station has been made. For five years the average annual rainfall has been 61 inches, distributed as follows:

Average for—	Inches.	Average for—	Inches.
January	4.42	July	6.21
February	6.52	August	8.03
March	4.51	September	4.94
April	3.39	October	3.06
May	6.68	November	1.81
June	8.42	December	3.50

A fuller examination of the record shows that 14 times in five years has the monthly rainfall been less than 2½ inches. Of these, 6 have occurred in the growing season; 3 in April, 2 in March, and 1 in May. Then, at least 6 times in five years could an additional supply of water have been provided to our crops with profit. Yea, more; it is now confidently asserted that 25 acres under ditches, with intelligent artificial irrigation, will produce more than double that area naturally watered.

Irrigation, then, should have been used advantageously many times in the last five years, even when the monthly rainfall was an average one. The entire sugar belt of Louisiana has been visited this spring by an unusually protracted drought, causing great injury to late planted cane and retarding the growth of both fall plant and stubble. At the Sugar Experimental Station there fell, on March 16, 1.44 inches of rain. From that date to May 4, only 1.48 inches fell, distributed in six showers, at intervals of nearly a week. It was therefore very dry and crops of every kind began to show the want of moisture.

A plan of irrigation was devised and steps taken to execute it. On Monday, May 4, the pump was started and 3 acres of plant cane was saturated with water. The operation began at midday and closed soon after dark, letting the water remain on the cane all night. The work was well done, in fact successful in every respect, but the fruits of the work were destroyed, for while the land was thus under water at 8 p. m. there came a terrific storm, a perfect waterspout, accompanied with hail, lightning, and thunder. There fell in about one hour 1.6 inches of rain.

This rain, while a perfect blessing to this community, for it was confined to a small area, was destructive to the experiment. However, early the next morning the quarter drains were opened and the water let off in the ditches, and up to date there are no visible signs of injury to the cane irrigated. The method of irrigating was a simple one. The plots on this station are a half acre wide and extend in length entirely across the field. Between each plot is a headland or drive 15 feet wide; a quarter drain separates each plot from the headland. There are no quarter drains in the interior of the plots. The ditches run at right angles to the plots. When these grounds were used for the exposition a complete water works was established for the entire park.

Two underground pipes of theirs cross our station at right angles to our plots, one 16 inches in diameter the other 6. Where these pipes cross our headlands they were tapped, and proper sized short pipes with plugs inserted. These pipes were arranged so as to discharge into quarter drains.

The water flowed from the quarter drains down the middles of the rows, and when they were full and the moisture appeared on the top of the rows, the quarter drains were dammed and the water directed to another plot. Ditches were crossed by wooden troughs large enough to convey the flow of the water. By this experiment it was found that every plot on this station (nearly 50 acres) could be successfully and easily irrigated.*

The first experiment was interrupted by a light rainfall. The dry weather, however, still continuing it was decided to try irrigation once more. On 10 acres of land without underdrainage, water was turned on for eighteen hours; 7 acres were in corn and 3 in fall cane. The tem-

* Louisiana Sugar Planter, May 16, 1891.

perature of the water was found to be from 70° to 71° F. Five acres tile-drained and planted in stubble cane were then irrigated. The first irrigation was that by flooding. The second would be that of sub-irrigation. Some difficulties were met in the lay out of the several plats, of which there were five, being tiles 3 inches in diameter and placed 40 feet apart, by each string running into a common main 5 inches in diameter, discharging at the lower end of plat 3. It was determined to irrigate plats 3, 4, and 6, and leave 5 and 7 without water. Plats 6 and 7, the last tile-drained and used in ditching, were not thoroughly compacted. Hence, one of the plats consumed water too rapidly, preventing equal distribution upon the other plat. After partially closing the 5-inch discharge pipe, the irrigation was continued more rapidly. All the underlaid plats by tiles were found to have been subirrigated. Three of the plats were served by surface irrigation or flooding. The report in the Planter states the result as follows:

The tiles are 4 feet deep, and the water had been therefore forced up through a layer of earth of this thickness. Thus both irrigation and subirrigation had been demonstrated. After eighteen hours the pump was stopped, the plats left full of water and the obstruction in front of the main pipe removed, and all retired to await the results of the morning. At 6 o'clock it was found that nearly all the water left on the plats had been removed during the night by the tiles, and it was estimated that a few hours more would have removed the last visible water, thus showing the value of the tiles in removing excessive rainfalls. Patches of sorghum, cowpeas, and Peruvian cotton occupying a part of tile-drained area were also surface irrigated. It may be mentioned incidentally that about 2 acres of corn first irrigated was unintentionally flooded again next day, making nearly forty-eight hours of inundation. The results of these experiments are plainly visible. The irrigated corn is in marked contrast with that unirrigated, both in size and general appearance. The cane is growing rapidly from the effects of its recent baths, while the sorghum, cotton, and even cowpeas are giving striking evidences of their superiority over those not irrigated. Not a single yellow stalk or "sere and yellow leaf" is anywhere visible from the effects of irrigation, while a dark green coloring, everywhere to be seen, gives striking evidence of its value.*

* New Orleans Planter, May 30, 1891.

FLORIDA.

The conditions of cultivation in the Peninsula State tend rapidly to impress the need of water conservation and distribution upon the intelligent planters, orchardists, and truck-farmers thereof. They are engaged in raising crops of large commercial value and can not afford to depend upon the uncertainties of nature. The soil is largely unretentive of water, and the temperature, as well as rainfall, at the growing season requires careful attention, with the husbanding of resources adapted to the deficiency and wants that arise. The rainfall being uncertain while the heat is great, irrigation becomes an essential part of the economy of farm and orchard. In all directions then there is an active effort to supply the want of precipitation and the loss caused by evaporation. It is conceded on all sides that the lightest and most barren of Florida soils can, with plenty of water and a modicum of fertilization, be made very productive. The Office of Irrigation Inquiry has received the following accounts of artesian wells and of irrigation plants in use for the utilization of those and other supplies: The most successful and as it probably is also the most thoroughly practical experiment yet made in irrigation by artesian water is that of Thomas H. H. Hastings, of Hastings (Merrifield post-office), in St. Johns County. Mr. Hastings is a Northern man, who, on "flat woods" land, cultivates early vegetables on an extensive scale. The results of his efforts, both in irrigation and maintaining the temperature in his "cuke" or cucumber and other forcing houses, have attracted wide attention. In answer to the inquiries of the Irrigation Office Mr. Hastings furnishes the following particulars:

The average is a flat pine wood land, with a clay subsoil from 12 inches to 2 feet below a rich top soil which can be ditched with a subsoil plow, said ditches carrying and holding water as well as piping. My beds are all laid off 20 feet wide, ditched each side; the water percolating on top of the clay, moistening the entire ground to the top. I can completely flood my beds, washing off and drowning outworms and caterpillars.

The cost of clearing and preparing, drainage, and ditches, is \$55 per acre; palmetto scrub costs more; fencing is extra.

"My well is 239 feet deep, with a four-inch bore. Total cost was about \$450. Flow of water sufficient to irrigate from eighty to one hundred acres. Force, from about three to five horse power. Natural flow upwards, about thirty feet. Have fine water-works system from a one-inch pipe attachment to well in my house; bath room in second story of my house. Can attach turbine water wheel.

As to the system of planting and water utilization, Mr. Hastings says:

Did not plow the whole ground; had no time. Dug trenches, put in compost, hoed the grass between trenches, which are 4 feet apart, built tomato frames out of rough boards, 150 to 200 feet long, 5 feet high to the north, sloping 22 feet to the south, where frames are 2 feet high. Use prepared heavy grade waterproof cloth curtains, which I roll down over the plants on cold frosty nights. Found the curtains perfect protectors from frost. Use same curtains in summer to protect plants from heat of sun. The sun always shines in Florida unless it rains, which is very seldom, except in the rainy season—the months of June, July, and August. I dig ditches outside and around the frames, filling them with water to irrigate the plants in the trenches, thence turn the water loose, and the same ditches answer for drainage and for trenches.

In his "cuke" house (which is 165 feet long and 22 wide, costing about \$1,400) Mr. Hastings uses his well water for heating. He says that in this house the—

Two side benches are 3 feet wide, my two middle benches are 5 feet wide each, two rows to a bench. Moisture and heat are furnished by water at a temperature of 79° from my well by permitting this water to run all frosty nights underneath the benches the entire length of the house.

Messrs. Hastings and U. J. White (whose statement follows Mr. Hastings') own between them over 12,000 acres. During the past season they harvested 400 acres in rice, averaging from 75 to 100 bushels per acre.

Mr. Hastings writes:

This was our first year's planting, on new land, only broken about eight months past. This is upland rice. Requires no more water than used for truck gardens. We expect to get from \$1.10 to \$1.25 per bushel for hulled rice. Will lose from 30 to 40 per cent in hulling, according to quality of rice. In August, 1890, I began my improvements, and did my first plowing. Mr. White began a year and a half earlier. The rice straw, when properly cured, furnishes excellent ensilage and feed for all kinds of stock, which eat it clean. * * * We will buy no more hay. Am planting now Irish potatoes, early turnips, and preparing ground for planting Bermuda onions; also planting celery seed in hot beds.

Mr. Hastings, in replying to office inquiry, states that in his neighborhood there are seven artesian wells, and within a radius of 7 miles some twenty, of which thirteen are used only for orange orchard irrigation. For fruit a sandy soil is used. In drilling for water, the first flow was obtained at 190 feet, the second at 239. The pressure is 10 pounds to the square inch, and the water rises above the surface about 30 feet. Temperature ranges from 74 to 79° F. No change seen in the flow, and the water is slightly sulphurized, but very clear. For irrigating about 100 acres from 3 to 5 horse-power is used.

A committee report read before State Horticultural Society, in May, 1891, describes their visit to the irrigated farms of Messrs. Hastings and White. Of the first named the committee says that Hastings' was not in existence in August, 1890. They state:

We soon discovered the great factor of it all in a 4-inch artesian well. This well is but 250 feet deep, yet the volume that rises is enormous and with such force that no pumps are needed to elevate the water to any part of the house or barn. The temperature of the water remains at about the same—79 degrees—the year around, which is a great advantage in gardening during the winter season. Close to the well the "cuke" house is built, being 165 by 22 feet, containing four beds, which run the whole length. The house is covered with glass and built similar to green houses North, only that it does not have to be so strongly protected against cold and has no steam-heating apparatus. The heating of this house during the cold spells that occur during December, January, and February is quite novel as well as original, and we venture the assertion that nowhere in the world is it done the same way. When the "signs" indicate that a cold night is approaching the well is opened and the stream of water is conducted to the cuke house, where it flows under the beds in a stream from 3 to 6 inches deep. This current of water keeps the temperature at an average of 69 degrees on cold nights, frequently making a difference of from 20 to 30 degrees between inside and outside.

After describing the tomato frames and the prairie garden the report goes on to say that—

All this was done with the aid of irrigation, the artesian wells furnishing the supply, although nearly half a mile off. Irrigation is done by means of ditches dug one side of the field. When a certain piece of land is needing water the trenches on both sides of it are dammed up and the water is allowed to fill the intervening trenches until level with the surface, and is then dammed in and left to percolate through the soil, which it will do in a very short time.

Of the rice culture it is said:

After vegetables are all harvested and the land plowed it is planted to rice and the

water turned on. In a great deal shorter time than one would think the ground is thoroughly saturated and the rice sprouts, and a good stand is the result. Thus the land can be kept in continued use the year round. All that can be done on this land remains yet to be proven, for the work that has been done is only a beginning, for it would be impossible for any one or two men to develop it in so short a time.

U. J. White, of Merrifield, now irrigates and cultivates 350 acres by means of four artesian wells, each yielding 300 gallons per minute, or in all 1,200 gallons each twenty-four hours. The water is heavily charged with sulphur. Drilling began in October, 1889, and was not completed until February, 1891, when the last well bore was made. The water rises above the surface a distance of 30 feet; the temperature is 74 degrees; there is no perceptible diminution of flow; the casing is 4 inches clear, through hard rock, to a depth in different wells of from 150 to 250 feet. The cost was from \$200 to \$400.

The drainage ditches on the farm are used to carry the well water for irrigation, flood-gates being put in at needed points. Main ditches are filled from the wells, and the water then backs into the laterals and furrows. The land is very level, with a clay subsoil, averaging 18 inches in depth, and materially aids the retention of the water about plant roots. The drainage system prevents undue filling of the soil. The rice fields are flooded by the throwing up of dikes around and then flooding the basin thus formed by water from the wells. The cost of preparing land is estimated at \$20 per acre, and the cost of irrigation plant at \$5 per acre. The cost of the four wells did not exceed this; certainly a very cheap system. Mr. White is enthusiastic in support of his own methods and results. There is in all 500 acres under cultivation by irrigation in his neighborhood. Fruits, semitropical and temperate, vegetables of all kinds, peas, beets, etc., and rice are the principal crops. The average returns under irrigation, except fruit which is large, is reported at from \$50 to \$60 per acre.

The visiting committee of the State Horticultural Society, whose report we find in the *Florida Agriculturist*, published at Deland, gives the following in relation to Mr. White's work:

We found Mr. White busy shipping cabbages from a 40-acre tract, and trying to figure out how much he would make at \$17 net per ear load, a large prairie of 400 acres, nearly all of which is covered with a crop of rice just coming up. This land three months ago was in its virgin state. Right through the center of this tract a canal is cut which is about 3 miles long. Into this canal the water from three artesian wells is turned and from here it is carried to all parts of the rice field. One can see a rice bed $1\frac{1}{2}$ miles in length with water flowing at every 40 feet. Last year, on some trial beds of rice, Mr. White gathered nearly 100 bushels to the acre, and the product was pronounced as fine as any from Louisiana or South Carolina. Some South Carolina planters have become very much interested in it.

C. A. Bacon, of Ormond, Volusia County, writes at some length, saying:

In the year 1883 I had a 3-inch artesian well put down. The surface is 10 feet above high tide in the river, which, according to U. S. Coast Survey, is 13 inches above tide in the ocean. (We are located at the head of the Halifax River, 5 miles north of Ormond.) The well will cease to flow about 2 feet above the surface. At the surface it flows from 40 to 60 gallons per minute at high tide in the ocean, and 30 gallons at low tide. In drilling the first 30 feet we passed through shell 6 feet, then coquina and quicksand, the balance blue clay to 90 feet, where we struck the bed lime rock and obtained a small flow on top of the rock. The casing ceases at the rock. From the 90 feet rock to the 163 feet depth, where we finally stopped, we passed through at least fifteen strata of coralline rock, varying in thickness from 1 to 8 feet. Between the strata there were seams; sometimes the drill would drop 2 feet. We had an increase of flow at 108 feet, and the best flow was at 128 feet; no increase after that. The water seems to be unlike any other in the State; visitors say it is identical in taste to the "Blue Lick" water in Kentucky. The Department of Agriculture gave a qualitative analysis, viz.: Composed of chlorides and sulphates of soda, magnesia, potash, and lime, 280 grains solids to the gallon.

The first six months after the well was put down, I ran it in trenches around orange trees, guavas, etc. Since then it has run in a trench some 300 feet through my grove, within 8 feet of a row of orange trees, the next row being 12, the next 32 feet, and I can not see a particle of difference in the trees, or rather in their growth, either within 8 feet or 100 feet of the running water. I had about concluded to let the Lord do the irrigating.

This summer, however, I have built a cement wheel-pit, the bottom on a level with high (common) tide in the river; I have put in a 10-foot water-wheel; face plate on each end of shaft; two No. 3 Douglas force and suction double acting pumps, stroke $5\frac{1}{2}$ inches. The water from the artesian well 80 feet distance turns the wheel from three to four turns per minute, according to the tide in the ocean. One pump takes the water that (or a portion of it) carries the wheel in a $1\frac{1}{2}$ inch pipe, to a 5,000 gallon tank, located 500 feet from the wheel. The top of the tank is 50 feet above the bottom of the wheel-pit. The other pump, lifts fresh water from a driven well through the bottom of the wheel-pit in 1-inch pipe to barn, house, etc., and then joins the $1\frac{1}{2}$ -inch pipe, where the surplus goes into tank. The $1\frac{1}{2}$ pipe screws into the bottom of tank, so that my lateral pipes (1 inch) connect with it, to save piping back from tank. My wheel and pipes will now fill the tank in about two days. I have 1,400 feet of pipes laid. My object is to irrigate the home acre or rather the home 3 acres, flowers, and small fruits, etc. I can attach at the farthest hydrant 100 feet of $\frac{3}{4}$ -inch hose and throw the water 35 feet from end to nozzle; can attach a whirlingig to hose and irrigate a circle 50 feet in diameter. I am well pleased so far; but, alas, man is never satisfied. I have a sprocket wheel on wheel shaft, am negotiating for a 4-inch well, and mean to make the old wheel hum, turn my grindstone, and cut my feed. On my wheel I am using about 40 gallons per minute, with a fall of 6 feet. We are convinced that on our droughty soil a little water is worse than none. When we know that an inch of water on an acre weighs a hundred tons, we begin to appreciate the irrigation system. I am making basins around my trees and plants, will put in fertilizer mulch, and keep wet. I believe there are spots on my place that have not been soaked for three years. My house is 2,000 feet from the ocean, near bank of Halifax River.

The Rev. Lyman Phelps, of Sanford, in Orange County, writes that—

In the section about Sanford, in Orange County, there are many artesian wells, but none used for irrigation. Some fifteen months ago I began work on a 3-inch well to see if I could get water for irrigation, and to study the geological formation. The land lies on the north side of Lake Jessup, in Orange County, and it is 16 feet above the lake at high water. There is a slight sandy loam on top. At 3 feet we struck clay mingled with decomposed shell; at 20 feet the amount of shell had greatly increased; at 36 feet and on to 46 there was little but shell, then a strata of blue clay of $4\frac{1}{2}$ feet. Water began to flow, but only a small amount—about 50 gallons an hour. From thence on to 96 feet it was shell and clay. The flow began to increase and all along down from 53 feet I encountered nodules of phosphate rock, black and brown, which rolled under my drill and impeded the work considerably. From 96 feet down shells began to flow out in large varieties—as large as could come up through a 3-inch pipe. They were oyster, clam, muscle, periwinkle, needle scallop, bits of the back of turtle, etc., which looked precisely as though they were just picked up on the coast. I drove the pipe 110 feet and drilled 124, when the water rose 19 inches above the pipe, which was then two feet above the surface. Putting on 20 feet of upright pipe the full flow rose over this. I took off the 20 feet and put on 4 feet of upright pipe and an elbow with 10 feet of lateral. The pressure is sufficient that the water running out of this lateral falls 4 feet ahead of the end of the pipe in a fall of 6 feet. The shells continued occasionally to run off. I have made no quantitative analysis of the water. Temperature is 78° F. There is a trace of chloride of sodium, more sulphate of soda, and some magnesia; also, some sulphurous gas, which quickly disappears in the air. All this tells us how comparatively new Florida is. The cost of this well was about \$102; it was put down by hand derrick, four colored men working with us, in four days. The pipe is double extra thick, and probably it was unnecessary to have it so heavy, but safe. This well is for an experiment, when I shall have set a grove, and note results. The timber is remarkably heavy on these lands. Some of the cabbages are 60 inches in circumference and 70 inches to top.

I am satisfied that one-third of the cost of fertilizing will be saved by these wells, and much also in cultivating. The water of my well is light and delicious for drinking. Last winter by steam pump I put 40 pounds of water once a month on trees heavily laden with oranges, and kept it up for four months. There was no stirring of the ground. The trees kept their fruit and looked extremely well on the 15th of September. Those adjoining which had no water looked like overtaxed willing horses, all gone to pieces, discouraged, and broken down.

From Artesia, Brevard County, Mr. J. H. Hogan forwards to this

office a clear, concise account of a well at that point. It is located, he says—

In Sec. 11, T. 24, R. 87, and was let by contract to bore 300 feet at 75 cents per foot. The bore was to be 3 inches in diameter; work commenced about April 1, 1890, and was finished about May 1, being piped down 100 feet, the 3-inch iron pipe drill passing through tough blue clay to the depth of 245 feet, then struck very hard rock 14 feet thick. The progress through this was very slow. After passing this a little water came and at 285 feet a good flow. There was no increase in the flow on drilling 15 feet further; the water spouted 7½ inches above the pipe, the end of which was above the ground. This gave a flow of about 6,000 gallons per hour; the well has been opened for a year and the flow has diminished about 1 inch. I never had any way to pipe up the flow so as to determine the head, and can not tell whether the decrease is caused by sinking of the head or by obstruction in the bore. The temperature of the water is 75° F. No sand or fish have been thrown up. A qualitative analysis made at the New York Homeopathic Medical College gives the following:

Hydrosulphate of soda.
Sulphate of soda.
Hyposulphate of soda.
Chloride of potash.
Chloride of soda.
Chloride of lithium.
Sulphide of iron.
Alumina.
Silica.
Sulphur (in suspension).
Sulphate of potash.

Sulphate of soda.
Sulphate of lime (a good deal).
Sulphate of strontia (a trace).
Sulphate of magnesia.
Bicarbonate of soda.
Bicarbonate of lime.
Bicarbonate of magnesia.
Bicarbonate of iron.
Sulphureted hydrogen gas.
Carbonic acid gas.

I irrigated from 4 to 5 acres of land, using hose with small eyelets set in. The land is in orange trees, and the part in small trees planted is partly in vegetables. To lay the ground in pipe with hydrants, etc., so as to use sprinklers would cost for cement pipe from \$250 to \$300 per acre. Irrigating can not be done by the ditch system in this region; there is no clay subsoil, and little or no capillarity in the soil. No other crop is attempted here but oranges, and a few vegetables in the winter. Clearing the scrub or saw palmetto land costs \$75 per acre, hemlock land about \$45. As to the value of the land it is hard to say. From \$50 to \$100 an acre is asked for it.

Mr. E. S. Hubbard, of Federal Point, Putnam County, writes that he irrigates by means of an artesian well, located in Sec. 37, T. 9, R. 27, that is at Federal Point. Drilling began in February, 1890, and well was completed by May. The first flow was struck at 152 and the second at 182 feet. The water is quite soft, with impregnations of iron and sulphur, smelling strongly of sulphureted hydrogen gas, and deposits white sulphur in ditch. Pressure has not been tested. The average rise of wells when closed in that section is about 46 feet above sea level. The flow of Mr. Hubbard's well is 700 gallons per minute, and the temperature is 75° F. There is some decrease in flow, about one-quarter or 175 gallons per minute. The water is sufficient to irrigate 100 acres, but only 30 are now under cultivation thereby. The casing is 6-inch clear for 50 feet, balance in rock. The cost was \$5,165 for the 225 feet of bore, which showed the following strata:

Strata passed.	Thick- ness.		Total.
	Feet.	Feet.	
Clay.....	30	30	
Quicksand.....	18	48	
Soft sand and rock.....	2	50	
Hard clay, several kinds.....	75	125	
Gravel bedded in clay.....	3	128	
Thin strata of limestone.....	2	130	
Soft white clay and gravel, hard brownish-gray clay.....	10	145	
Thin rock gravel and clay.....	5	150	
Gravelly hardpan.....	15	165	
Hard and soft lime rock.....	10	175	
Gravelly clay.....	8	183	
Blue and gray clay.....	12	195	
Very hard and flinty limestone.....	3	198	
Coralline limestone, hard and soft layers, the water.....	43	241	

The water is distributed by means of drainage ditches which are dammed so as to make them subirrigating. The season is the three dry months of April, May, and June. The original cost of water is the amount given for well, etc., and the annual interest thereon of about \$40. The land is underlaid with clay at from 2 to 3 feet from the surface. There is a foot of quicksand between the clay and alluvium. It is very level and requires drainage, hence the use of ditches. The cost of maintenance and repairs will not exceed \$2 per annum. Citrus fruits and early vegetables are the products.

J. F. Tenney, of Federal Point, reports one artesian well in use for the irrigation of 8 acres in semitropical fruits. The cost of preparing land for cultivation is about \$30 per acre; for irrigation works, it is estimated at \$10, and annual repairs at 50 cents per acre, though Mr. Tenney says:

The work is so irregular and of such varying character that no just estimate can be given. The plant is so new that the annual cost can not be truly stated; I can only say that the cost will be nominal.

The well was begun in 1890 and drilling finished in 1891. There were six flows struck, each at 60, 80, 90, 100, 198, and 245 feet. Some sulphur and iron were found in the water, the lowest flow being purest. The pressure is about 15 pounds to the inch. The flow above surface is 23 inches when the well is open wide, with a flow of about 500 gallons per minute and a temperature of 72°. Five horse power is used per each 5 acres. The well is cased for 154 feet, with 4-inch bore. The entire cost \$350. The drill passed through sand, clay, coral formation, and thin strata of rock. Water was found in coralline rock about 50 feet thick, of a porous character, and mingled with marine shells.

Mr. J. G. Howes, of Florida, who is living in the neighborhood of Orange Lake, a successful and enterprising orange grower of that State, has a very interesting plant for irrigation purposes. The supply is from a small lake, 200 feet from the pump stand. The method is by sprinkling and wetting from the hose, and manner of use is as follows: The water plant consists of a small pool or lakelet, the water of which is lifted and distributed through the agency of one duplex steam pump, with 8 by 10 steam and 6 by 10 water cylinders, with 8-inch suction, and 3-inch discharge ports. There is a 15 horse power boiler. A 4-inch suction pipe connects the lake with the pump—a distance of 200 feet. The water for distribution is forced through a similar pipe for half a mile, entering the orange grove on the north side and running straight across it to the south. The description proceeds:

At intervals of 60 feet along this main are placed 24-inch plugs as hydrants, and when the plant is to be used 24-inch hose, in 50-foot sections, is attached to one end of these plugs, and stretched out between two rows of trees to the edge of the grove. The rows of trees are 25 feet apart, and two men operate one line of hose. The work of wetting down the trees and ground begins at the edge of the grove, and we will go through the operation with them and then we will know as much about it as they do. The man who handles the nozzle stands in the center of the square formed by four trees, and wets them, as well as the ground between them, thoroughly. As soon as he has wet these trees sufficiently, pipeman No. 2 disconnects that section of hose at the coupling, 50 feet to the rear, and at once begins to water the next four trees; at the same time No. 1 takes the disconnected section of hose and carries it over and stretches it out between the next two rows; he then walks back to third coupling of the line of hose in use, and by the time he gets them No. 2 has got his four trees thoroughly watered. No. 1 then disconnects and begins the work of wetting down, while No. 2 takes his section of hose across and connects it to the section which No. 1 has just laid down, and then he hurries back to the fourth coupling and repeats the operation, and this is continued until the last section of hose is reached, and while one man waters the last four trees the other connects his section of hose to the next plug or hydrant, and then walks swiftly to the end of the new line, and when he reaches the end he finds

the water spouting out lively, and the operation is repeated. Two men will, in this way, water 8 acres of grove per day, and serve from 400 to 600 gallons of water per tree.

The cost of this plant and service is estimated at \$3,500. Amount of service rendered is summed up in the statement that it has easily "delivered at the end of 2½-inch hose, more than one-half a mile from the pump, 600 gallons of water in 58 seconds, with a boiler pressure of 75 pounds of steam.

Mr. G. Loutrel Lucas, of Eden, Brevard County, uses for irrigation of orchard, etc., an artesian well, located in Sec. 9, T. 37, R. 50, 41 E., the work on which commenced July 2 and was finished August 25, 1890. The present flow was struck at a depth of 811 feet. Other flows were struck at 700, 760, and 800 feet. The elevation at surface is 13 feet above sea level. The water at 800 feet was strongly impregnated with sulphur, but free from salt. The pressure when closed is 10½ pounds to the square inch. The gauge rises gradually. The rise in 3-inch pipe above ground is 20 feet, temperature is maintained evenly at 70° F. The flow after the well is opened several days remains the same. There is a little fluctuation at times in the flow since the well was first opened, but the average is not less. Sometimes sand is thrown. This is the first report on that head that has been received. The quantity is not large. The inside diameter of casing is 3 inches. The casing extends for 230 feet; the balance being in impervious clay. The cost of the well is stated at \$600. Pipe is open at bottom. The following is the record of strata and feet passed:

Strata passed through.	Thickness.	Strata passed through.	Thickness.
	<i>Ft. In.</i>		<i>Ft. In.</i>
Surface sand	3 0	Blue clay	3 0
Yellow golden sand	6 0	Shell rock	0 2
Quicksand, worst kind	140 0	Blue clay	2 0
Cemented sea shell, fine	1 0	Rock	0 2
Quicksand	30 0	Blue clay	1 0
Cemented sea shell	2 0	Rock	0 5
Quicksand	37 0	Blue clay	30 0
Stiff blue clay	410 0	Soft spongy rock like raw cotton	20 0
Medium rock	0 2	Hard rock with clay in holes	5 0
Blue clay	3 0	Water rock, first flow	26 0
Hard flint rock; nine days drilling to get through	0 1	Water-bearing rock	111 0
Blue clay	5 0		
Flint rock	0 3	Total	811

This well is used to irrigate orange and lemon trees on about 1 acre. Pineapples are also planted between rows. Irrigation is reported to be a success.

Mr. George W. Wilson, of Orange Lake, Marion County, reports about 200 acres under irrigation in his neighborhood. The ordinary means of supply is from small lakes, lifted into tanks or by direct pressure from standpipes, then distributed by hose. The cost of such plant, pipe, 3-inch main, 2-inch laterals, and 1½ flow from hose nozzle, is about \$50 per acre. The annual cost to user per annum is placed at \$5 per acre. Mr. Wilson himself irrigates 50 acres of orchard and vegetable land. The product is greatly increased by the application of water. Mr. F. E. Buffum, of Stanton, in same county, reports the use of a small lake supply in the irrigation of 18 acres of citrus land. A weir is used for outflow and a steam pump to lift the water. The main pipe is 2,000 feet in length and of 2-inch diameter, and the tank has 13,000 gallons capacity. The cost of preparing clay land for citrus trees is about \$15 per acre. The cost of irrigation plant is not given.

The Orange City Water Works and Irrigation Company, started by Wisconsin investors, is located at Orange City, in Volusia County. It has commenced the work of construction and is expected to be in operation early in 1892.

At Green Cove Springs, in Clay County, a local irrigation company has been formed. The supply will be obtained from a 10-inch artesian well in process of being drilled. Mr. H. B. Stevens, of Citra, in Orange County, reports 200 acres under irrigation, work begun in 1891, at a cost for pump and distributing plant of \$1,000. The cost of irrigating truck gardens and orchards at or near Jacksonville is reported as from \$50 to \$100 per acre. The soil is sandy and ditches are not used. Steam pumps are necessary and also pipes and either hose and nozzle or revolving sprayers are used. There is marked appreciation in Florida of the latter appliance, which is similar to that so largely used and employed for sprinkling city lawns. The largest reclamation scheme for cultivation purposes of which the Irrigation Inquiry has any knowledge is found in the following account of the plans proposed for utilizing the Halpate saw-grass section, embracing over 11,300 acres. It is now under control of the Sebastian Sugar, Land and Improvement Company, which proposes to thoroughly drain the whole area, which now forms an impassable swamp of the extreme headwaters of the St. John River: "At ordinary times this area has from $1\frac{1}{2}$ to 2 feet of water over its surface, but during the rainy season is from 4 to 5 feet deep." The whole country, for from 20 to 50 miles, is nearly a dead level in the rainy season, and the water stands on the prairies 2 to 4 feet deep. It will be necessary to surround the tract with a levee. The tract to be reclaimed is about one-third prairie and about two-thirds saw-grass ponds. It is $6\frac{1}{2}$ miles from the Indian River, famous for producing on its banks the best oranges in the State. The drainage will be into the San Sebastian River, a considerable stream, emptying into the Indian River (which is a tidal lagoon).

The fall from the ordinary surface of the water in the swamp to tide water in Indian River is 22 feet, and the length of the main canal will be 18 miles, and 54 feet wide on the bottom, 8 feet deep, with slopes of 2 to 1. The total length of the branch canals, including the boundary or intercepting canal, will be 95 miles, without counting the innumerable ditches. The levee will be 60 miles long and 30 feet wide on top, 6 feet high, slopes 2 to 1.

There are three large but shallow streams, some 600 to 800 feet wide, now entering the tract from the west, which will be diked out and a new derivation channel dug for them. The Great Sawgrass lake, 1 mile north of the tract, will be 4 to 6 feet above the water level in the tract when lowered by the canals, and this will have to be kept out by levees and sheet piling. The slope of the main discharge canal will be such as to allow steamboat navigation.

The soil of these saw-grass ponds is a very rich black mud, 10 to 25 feet deep. From the experience of the Disston Company, who have reclaimed and planted large tracts of this kind of land in the State, it is found to produce abundantly. They have raised on similar land, without fertilizing of any kind, 6,000 pounds of sugar per acre; 30 barrels of rice, worth \$3.50 to \$4 per barrel; 60 bushels of corn, and are now experimenting with success with tobacco. The soil is peculiarly adapted for all kinds of garden vegetables, which can be placed in the northern markets about February and March. It is also exactly suited for bananas and other tropical fruits, and the drained prairie will raise pineapples, guavas, peaches, pears, mangoes, grapes, alligator pears, etc. Irrigation is to be resorted to after reclamation (drainage) is accomplished, so as to insure crop security.

SOUTHERN ALABAMA.

Prof. J. P. Stelle, of Fort Worth, Tex., agricultural editor of several important southern newspapers, a writer and scientist of ability, acumen, and insight, presents vigorously reasons for the practice of irrigation in coast lands of Alabama. In a recent paper* Mr. Stelle, after alluding in flattering terms to the work of this Department through the Office of Irrigation Inquiry, says:

In the very near future the most valuable agricultural lands will be such land as can be easily and inexpensively watered, and it don't call for much thinking to enable one to see where this will place the Gulf Coast region east of the Mississippi River.

The region is literally broken up by broad valleys, down which flow perpetual streams of greater or lesser volume. These streams are sustained by living springs and lie in beds but a few feet below the general level of the bottom lands of the valley. There is a first bottom and a second bottom. The first bottom, immediately bounding the stream, is exposed too occasional inundations, but it is comparatively narrow; the second bottom is above all overflow, and the fall of the stream is usually great enough to throw it upon this second bottom land by ditches only a mile or so in length. The valleys open out on broad expanses of level lands making up the coast proper, and it would be no trouble whatever to irrigate every acre of these lands by turning the streams upon them. Ample water comes down the stream to meet every requirement in that direction if correctly applied.

The cost of putting all these lands under irrigation from Chickasabogue and tributaries would be so small that in California, New Mexico, Colorado, etc., they would consider it scarcely nominal, for there they often carry their irrigation water through ditches, flumes, and aqueducts 30 and 40 miles, and think nothing of it, getting less water than we might get with half a dozen miles of plain, rockless ditch. Now, what would be the outcome of an irrigation arrangement of this kind?

In the first place the system would cost comparatively little. There are no rocks to cut through, and no need of walling. If it was built by a syndicate, that syndicate would first buy up the lands. These lands could be had at from \$2 or \$3 an acre, but you may put it a little higher on the average if you wish. So soon as the system was complete every acre of that land would go at from \$75 to \$100 per acre. The irrigation ditches would still remain the property of the syndicate, and the land purchasers would be required to pay a low water rent annually, which could be so shaped as to bring in a good interest on the original investment.

The man who has studied irrigation in the Southwest can easily see what would become of an irrigation arrangement like this. All the lands under the system would be promptly taken and would be converted, as it were, into a continuous village. Churches, schoolhouses, and factories would soon be built, and the now blank and lifeless region would be converted into a very hum of industry. Intensive culture would be prosecuted; fruits of nearly all kinds would be a success, and other crops would be made to lap one upon the other the year round. The early crops would be shipped to Northern markets, as now; the later crops would be consumed or worked up at home. Great canning, evaporating, picking, and central sugar plants would spring into existence for putting the later crops into shipping shape, to say nothing of great spinning and weaving plants to work up the immense sea island cotton product that would certainly be a result of irrigation.

But the best of it is yet to be told. As already intimated the spring crop truck farmer must pay out the best portion of his returns for fertilizers. It is a fact well understood and settled that under irrigation less than one-fourth the quantity of fertilizers as are now employed would go as far to feeding plants as would the whole. The fertilizers now employed to make the spring crop would be ample, under irrigation, for keeping a succession of crops flourishing the year round.

* Mobile Register, November, 8, 1891.



WELLS FOR IRRIGATION IN TEXAS.

In the progress report for 1890, made to this office and the Department, Assistant Geologist, Prof. Robert T. Hill, of Texas, referred to a successful irrigation work carried on by Mr. William C. Lanham, of Glen Rose, Somervell County, who has profitably irrigated 30 acres with an 8-inch artesian well, which flows about 400,000 gallons of water every twenty-four hours. Mr. Lanham does not use manure and raises staple crops only, such as corn, cotton, and sugar cane. His land is reported to be precisely the same in character as that which produces without irrigation an average of 25 bushels of corn to the acre. The irrigated land gave in 1888, 75 bushels; in 1889, 66 bushels, and in 1890, 40 bushels to the acre. That not irrigated gave from 250 to 500 pounds of cotton seed to the acre. In 1888 Mr. Lanham's irrigated lands gave him 2,200 pounds of cotton seed; in 1889, 3,000 pounds, and in 1890, 4,000 pounds. From ribbon cane he has a regular yield of 350 gallons of sirup to the acre. Several other experiments in the same neighborhood have met with equally successful results.* No one has irrigated alfalfa, clover, small grains or small fruits, which are most susceptible of very profitable irrigation. At Paluxy village, 10 miles west, there are two irrigated farms upon which cotton was growing in 1891, 2 bales to the acre.

Enterprises in operation on the Staked Plains region are already demonstrating the possibilities of reclamation. The reports of the artesian and underflow investigation (1890), and of the progress report for 1891, have furnished considerable favorable evidence, on this point. There has been a steady degree of progress during 1891, and the use of the phreatic waters for irrigation purposes has steadily increased. A settlement along the line of the Texas Pacific, Martin County, has had quite an experience as a pioneer in coöperative colony effort. The aim was to create small farms devoted chiefly to raising fruits and fine vegetables for early markets. From the outset the irrigation needed has been obtained from nonflowing wells, the water of which, obtained at moderate depths, is lifted to the surface by means of windmills. The objects of the company now operating at Marienfeld is given in the annexed statement:

- (1) To grow fruits, vegetables, and general farm crops by irrigation and otherwise for profit. To market the products grown by this corporation in their natural state, as well as to can, pickle, preserve, evaporate, dry, refrigerate, or handle in any method necessary for safe transportation and sale.
- (2) To buy and sell fruit and vegetables and to pack for market the produce of others, for a consideration, after the methods enumerated above.
- (3) To promote horticulture, agriculture, vine-growing, and general farming in Martin and adjoining counties in Texas by irrigation and otherwise. To acquire by purchase or otherwise, for the benefit of the stockholders of this corporation, parcels of land and to prepare the same for irrigation and to plant the same in trees, vines, and marketable products.
- (4) To contract with nonstockholders to plant and irrigate their lands for a suitable consideration.
- (5) To make preserves, pickles, and canned goods of every description, and also to make and sell cider, vinegar, wine, sorghum sirup, and manufacture other products of the farm in this line of goods. To erect and maintain the necessary buildings

and sheds for the storage, packing, and preserving, canning, and pickling of fruits and vegetables.

(6) To develop a water supply by means of digging or boring wells, or by erecting dams or tanks; to raise water by suitable pumping machines and to distribute the same by means of pipes, flumes, ditches, storage reservoirs, and other methods; and to secure, and if necessary to condemn in a lawful manner, the right of way for flumes, ditches, and water pipes for purposes of irrigation over lands not owned by this company.

(7) To contract with farmers and others desiring water for irrigation, to supply water in stated quantities for a stated consideration.

(8) To contract with nurserymen, fruit-growers, gardeners, foresters, and others for the establishment of orchards, nurseries, vineyards, market gardens, and forests of useful timber, as well as the establishment of factories engaged in the preservation in various ways of fruits and vegetables or manufacturing edible products of the farm.

There are more than 1,000 flowing wells in Texas, nearly all of them being found west of the ninety-seventh degree of west longitude. Several hundred have been bored during the year 1891. All this data is presented by the assistant geologist and is referred to only to emphasize the interest arising in the extreme South and Southwest over the practicability of utilizing the phreatic waters of that region. Their vast capability and adaptability for making secure an agriculture always rendered uncertain under high temperature, even when the rainfall, if properly distributed, is ample for industrial uses, has just become a matter of general understanding. Prof. Robert T. Hill has recently said in relation to the use of artesian water in Texas for irrigation, that in the development of such wells their use for irrigation was not dreamed of originally, but that now they are being widely utilized. In Somervell County, where rain is rather scarce and one-fourth of a bale to the acre is considered a fair crop, "I have seen," he says, "2 bales of cotton per acre and 250 gallons of Louisiana molasses raised per acre and 80 bushels of corn by the use of artesian well water."

The eastern half of the State is blessed with an abundant supply of rainfall, and hitherto it has been hearsay to say that rainfall was insufficient for agriculture in any part of the State. Sentiment is rapidly changing, however, and the irrigation idea is not only beginning to be tolerated, but applied to a great extent. There is no doubt that the whole agricultural aspect of the western two-thirds of the State, which lies in the region of uncertain rainfall, will be changed within the next ten years, and steps are rapidly beginning to be taken in that direction. The Pecos River in Texas will soon be utilized by the numerous ditches now constructing along its course, and many new canals are also taken from the Rio Grande. The chief area for profitable irrigation in Texas, however, lies in the heart of the State, coincident with the great fertile black prairie region. This area is blessed with one of the most abundant and unique water supplies in the world, consisting of artesian waters and springs. At Del Rio over 15 miles of ditch have been constructed to utilize the waters of a single spring, which breaks forth from an arid plain back of the city and flows a larger volume than the Rio Grande into which it empties. The San Antonio River has its source in springs of exactly the same character, which not only furnish the city water supply, but for 200 years have irrigated several thousand acres in that vicinity. San Marcus, Austin, New Braunfels, Georgetown, and other places have similar natural fountains which would irrigate millions of acres. This water all comes up through natural fissures from a deep source, and the springs might be called natural artesian wells, for wherever in the region characterized by these springs a hole is drilled to the underground supply magnificent artesian wells are





BOX IRRIGATION. PRIDHAM ORCHARD, LANORIA MESA, NEAR EL PASO, TEXAS.



TWO YEAR OLD JULY TREE. PRIDHAM ORCHARD, NEAR EL PASO, TEXAS.

secured. Mr. F. E. Roesler, C. E., of Dallas, who has served the artesian and underflow investigation as special agent, and the irrigation inquiry as a volunteer field agent for Texas, has recently declared that—

The farmer in the Rio Grande or Pecos valley, whom necessity has compelled to farm after rational methods, and who gets just as much if not more money for his wheat than does the ten-bushel farmer, can afford to sell his wheat for 50 cents per bushel and still clear from three to four times as much per acre. The same rule applies to the other crops. Then, again, as the irrigating farmer loses no time in waiting for rains to enable him to plow, he raises two or three crops on the same land while the rainfall farmer raises only one, and that often a small crop in the same time.

Long-headed farmers in Florida and Louisiana where the rainfall is from 54 to 60 inches a year, are beginning to irrigate extensively, and they find it profitable. Some of the growers of fruit in Massachusetts and New Jersey are beginning to learn that irrigation pays. But there are very few of these sensible men. Untold millions of dollars are swept annually into the Gulf of Mexico and the Atlantic Ocean, while other millions are expended for artificial fertilizers.

As a remarkable illustration of what water will do, and also as proving the economic importance of a phreatic supply, the following account of the Pridham Orchard, situated on the mesa about 2 miles outside of El Paso, is given. A personal examination of it was made by the special agent in charge during the summer of 1891. It is 10 acres in extent, planted with peach, plum, and pear trees, with a small portion in vines. This orchard is owned by a stock company and was planted as an experiment. Nothing more uninviting and desolate in appearance can be conceived than the Lanoria Mesa, as it is termed, on which the Pridham place is situated. The system of irrigation is peculiar, as well as original. Water is brought from a well, 122 feet deep, in which the water is raised to the surface by a windmill. The water rises 35 feet deep in the well. The bed rock is 17 feet thick. The trees are regularly set out and at the foot or root of each one is a hollow box or cube of common board about 18 inches in length by 6 inches square. This is set obliquely in the ground near the stock of each tree and vine. The water is discharged from the windmill into a large cask, set in a hand truck. It is then hauled up and down the rows and several gallons of water poured into the box or trough at base of each tree. This it is claimed allows a minimum amount of water to do a maximum of service, it being applied directly to the roots, causing them to grow downward and not spread on the surface as in flooding. Every tree is doing well in the orchard and was doing well at the time of the visit of special agent June, 1890. The soil is about 4 feet thick and is immediately underlaid by an impervious stratum of hard shale. There are several other orchards on this mesa, in which the same plan of irrigation is followed. Edgar B. Bronson, of El Paso, who is in the company operating this orchard, writes as follows:

That the least cost in 1887 was \$35 an acre (unimproved).

That 160 acres of this land sold last month (June, 1891) at \$17,000, or a little over \$100 an acre (unimproved also).

That the well, windmill, and fencing cost \$600.

That the well is a dug well 90 feet deep; there are about 15 feet of water in the bottom, which we have never been able to pump dry or to materially lower.

That a 5-inch bored well would answer the same purpose and be much cheaper and more permanent.

That we have inclosed under fence only about 10 acres, embracing about 2,000 trees, 200 grape vines, and a few berries.

I can not state to you the amount of water in gallons furnished by this well, but can positively that by our experience with the well on the 10 acres now cultivated that it furnishes abundant water for the cultivation of at least 25 to 30 acres in trees and vines.

The trees and vines planted cost \$500.

The maintenance of the place costs us for wages and fodder \$45 per month.

In the cost of well and windmill is included the price paid for one horse and harness, one cart and one water tank, used for distributing the water in irrigation.

As you have seen, our method of irrigation is peculiar and perhaps original. Immediately beside each tree is placed a wooden box 6 inches square, made of inch boards, 2 feet long and sunk 18 inches in the ground. Six inches above the bottom this box has 2 inch holes bored in it. We put no water on the surface of the ground. The water tank is driven down between the rows of trees with pipe and faucet at rear of tank, and the boxes at either side are filled with water as the cart slowly travels down between the rows. In this way not one drop of water is lost by evaporation or by the saturation of any soil which is not the immediate direct feeder of each particular plant irrigated. Moreover by this box system we carry the water entirely below the roots of the trees and thus foster a downward growth of the roots instead of leaving them to turn upward toward the surface, as inevitably results where irrigation by surface flooding is practiced.

With us of course this box is only experimental, to show the capacities of the soil, and the possibilities in the economies in the use of water. The cost of the maintenance of the place is high, but is a natural result of a condition where we are compelled to pay in cash for every variety of improvement, or stroke of labor bestowed upon the land. We find the irrigation proposition, however to be a sound one, and certainly as cheap, if not cheaper, than a canal proposition, with the added advantage that each individual farmer entirely controls his own water supply.

There are about seven or eight similar orchards and vineyards on the mesa irrigated from wells. I don't know the acreage planted, but should think there are from 10,000 to 20,000 trees and vines growing there.

The most extensive canal system yet operated in Texas is that of the Pioneer Canal system in the Pecos Valley, Reeves County, and adjacent territory on the west side of the river. In the neighborhood of Pecos City, where there also are some twenty-five flowing wells, there are nearly 20 miles of ditch constructed, with 20,000 acres under it. On the east side about 12 miles are completed with over 10,000 acres to be served. When the east side system is finished at least 100,000 can be irrigated. About 12,000 acres were under cultivation by irrigation during the past season. The area is as good for fruit as cotton, for early vegetables and berries as for small grains and roots. It is in the sugar-beet belt also.

AGRICULTURAL HYDRAULICS.

CHAPTERS ON WATER, ITS MANAGEMENT, CLIMATE, INTERMITTENT IRRIGATION, AND THAT OF PLANTS USUALLY CULTIVATED.

[Translated from the French of M. J. Charpentier de Cossigny, by Mrs. A. F. Wood, Office of Irrigation Inquiry.*]

THE CONSTITUENTS OF WATER.

[Chapter I, pp. 6-17.]

Mineral substances in solution in water.—Water never exists in a natural state in perfect purity. In reaching the surface, whether by passing through the thickness of the most permeable strata, or coming from the deep fissures, whence they issue in the form of springs, they carry in solution the various mineral substances which compose the rocks with which they have been in contact during their passage. The substances most common and abundant in water are lime, magnesia, aluminum, oxide of iron, mixed generally with siliceous and carbonic and other acids. Most of these substances are also contained in the tissues of vegetables and are found in their ashes.

A fact which is evident in acknowledging the presence of these attributes in water is that when the ground is irrigated not only is it benefited by the application of the water to the soil merely, but the water also introduces into the soil the various mineral substances held in solution, to be used by the plants under the most favorable conditions of assimilation. These substances are especially important to the well-being of the soil to be irrigated when they supply those essences which are entirely absent and which would be eminently beneficial. Their absence is often noted. M. Paul de Gasparin has found that water springing from soil reputed to be exclusively calcareous in character has held in solution important quantities of siliceous matter.† On the contrary, I have several times had occasion to observe on several localities situated on the same perimeter as Sologne, that when the cultivated ground was completely deprived of lime the water of the springs was highly charged with calcareous salts—a fact which is sufficiently explained by the existence of large deposits of marl contained in the subterranean regions traversed by these waters. Such water used in irrigation not only furnishes an element indispensable to the crops, but, in the long run, even succeeds in improving the character of the soil itself.

*Second edition, Paris, 1839. Encyclopedia of Public Works.

†Journal of Agriculture, 1872, t. IV, p. 169.

It has been found by M. Hervé Mangon, who has made numerous experiments on the use of irrigation water, that in several cases the mineral substances supplied by the water was in excess of the needs of the crop.

Among these mineral essences are two, which, on account of the universal need of them by all plants and the scarcity of their deposition by nature in cultivable soils, are important, viz, potash and phosphoric acid. Potash does not appear in the analyses of many kinds of water, especially in those of ancient origin, and as for phosphoric acid, there is not a single analysis in which it is mentioned. But we need not conclude from these facts that these substances are positively absent in the generality of natural waters. It must be remembered, also, that it has been but a comparatively short time that these essences have been sufficiently understood from an agricultural point of view, and we must also note the difficulty of correctly calculating and applying the very small quantities of potash and phosphoric acid necessary for plants. To determine these quantities with the requisite nicety would require the use of the most delicate and recent chemical processes as well as the skill of the most practiced experimenter.

However that may be, M. Sainte-Claire Deville has made analyses of the water of the rivers Garonne, Seine, Rhine, Loire, Rhone, and Doubs, and has found that the waters of all these rivers contain potash. Payen has found it in considerable quantities in the water of the artesian well of Grenelle at Paris. From an experiment made by him we may conclude that a field containing 1 hectare (2.47 acres), irrigated with the quantity of water generally used in France,* would receive therefrom as much potash as would be furnished by an application of 87,000 kilograms of stable manure.

It has been demonstrated that rainwater dissolves the potash, little by little, in granite soils. It is equally true that this water also attacks the phosphates found in many soils and especially abundant in rocks of volcanic origin. There can be no doubt, then, of the existence of small quantities of phosphoric acid in most springs and in nearly all rivers.

It may happen that some of the water used for irrigation does not contain a sufficient quantity of these substances for the production of abundant crops; in such cases, in order that all the benefit possible may be derived, this deficiency should be supplied by adding the needed supplementary chemicals, which must, however, be carefully adjusted and carefully administered.

Nitrate of ammonia in irrigation water.—In the before-mentioned analysis of the waters of the rivers Garonne, Seine, Rhine, Loire, Rhone, Doubs, etc., made by M. Sainte-Claire Deville, it is found that matter exists therein in the form of nitrates. These waters, then, with the exception of the Garonne and Loire, contain nitrogen (azote) in the form of nitric (azotic) acid.†

The important influence of nitrogen on vegetation is well known. Water containing animal matter in a state of putrefaction (as in rivers after having passed through populous cities) is notably ammoniacal in its character. Rainwater itself, though the purest of all water, contains, at Paris, according to Barral, from 1 to 3 milligrams of ammonia and nearly the same quantity of nitric (azotic) acid per liter. The

* That is, with the quantity of water furnished by a continual and regular flow of 1 liter per second. This quantity would be 15,552 cubic meters in six months.

† Acid formed by a certain combination of nitrogen (azote) with oxygen is known either as nitric or azotic acid. This azote, uniting in turn with lime, potash, soda, forms the salts known as nitrates or azotes.

water resulting from the drainage of cultivated land is richer in azote than that from springs or rivers, a fact that M. Barral was the first to call attention to.

Gas in solution in water.—Water, especially running water, absorbs air. Gas and vapor are disengaged at the same time, and by means of some quite simple appliances they may be collected and analyzed.

It is well known that atmospheric air is a mixture (and not a combination) of two principal gases, oxygen and nitrogen, in the approximate proportions of a volume composed of 21 parts of oxygen to 79 of nitrogen. Air contains, besides, from 4 to 6 ten-thousandths of carbonic acid gas.

It must be observed that the oxygen and nitrogen, not being in combination, act separately, according to their affinity for the liquid, so that the water is always found to have absorbed, following the proportions of the atmosphere, more oxygen than nitrogen.

We will investigate the rôle played by the gases introduced through irrigation waters into the cultivable soil. Oxygen is not so much a food for plants as it is one of the principal agents in the complex phenomena by which the sap is prepared in the depths of the earth. It slowly burns away the organic matter of vegetable or even animal origin mixed with the soil; it transforms little by little the insoluble matter into a humus which is soluble and which can be easily assimilated by plants. The oxygen, moreover, holds and returns to the soil at need the sulphur found there in a state of sulphates (inoffensive salts), to the exclusion of the sulphurets, especially the sulphureted hydrogen, which last is frequently the product of putrid decompositions, and which is poisonous to plant life. Finally, this same gas—a life-giving agent par excellence—in encountering calcareous or alkaline matter in the soil, causes the azote mixed therein to pass into nitrogenous forms. These azotes or nitrates are the richest and most essential principles in the successful cultivation of the soil.

As yet no experiment has been made determining the exact part played by the water in introducing azote into the soil, and we can only advance arguments in favor of our presumptions. Is this azote finally disengaged into the atmosphere? It would seem probable for that portion corresponding to the water which is evaporated on the surface of the soil under the combined action of the sun and winds. But this is only a small portion of the irrigation, for independently of the limited part which sometimes penetrates to great depths in the earth, there is still another important portion which, after having passed through the plant with the running sap, is returned by transpiration to the atmosphere. But vegetables do not exhale any nitrogen. There is reason to believe, then, that the azote found in solution in that portion of the water of which we are speaking must have become fixed there either by the soil a little in advance of the penetration of the water into the plants through the roots, or else by the plant itself during the passage of the water through it. In the first case it would not have been impossible for a nitrification of the azote to have occurred, owing to the action of the oxygen and the alkaline substances contained in the water before its absorption by the plants. A gas dissolved in water is in a veritable state of liquefaction, and the molecules are infinitely more condensed than when they are in a gaseous state, which considerably augments the energy of the physical force. Who has not noticed, for instance, that the action of the air has no effect on iron nor on most other minerals when they are in a dry state, but that it oxidizes them as soon as water is introduced. Would it not also be possible for ni-

trogen, usually in an inert state, to become a more active principle when in solution?

M. Hervé Mangon has experimented upon a prairie by irrigating through a whole season. At each irrigation he has measured the quantity of water appropriated and also the quantity which has afterward escaped, not having been absorbed.

He calculated the quantity of nitrogen furnished by the soil by known agents and the quantity found in the crop itself, and found the last quantity in excess of the first. Whence comes, then, this excess, except from the atmosphere, and through what channels, under what influences, and by what chemical aid does this substance penetrate into the earth?

M. Georges has claimed that the azote (nitrogen) is directly absorbed by the leaves, but the truth of this hypothesis has not yet been demonstrated, and it is now generally believed that through the intermeditation of the soil and the roots azotic matter passes into the organisms of the plant.

But water contains in solution not only oxygen and hydrogen, but also carbonic acid in various proportions. But the carbonic acid found in the water could not be accounted for by the quantity found in the atmosphere without the intervention of other causes. One of these facts is that the water of the springs is more or less mixed with carbonic acid, and their water is more or less mingled with that of the rivers themselves, etc. On the other hand, Mangon found that irrigation water, running along in narrow channels on the surface of the ground, was found to be much more highly charged with carbonic acid than before its passage through this prairie. Might it not be by means of a similar phenomena that is produced during heavy rains on the surface of each field that the waters of a river are much more highly charged with carbonic acid at the time of high water than at low water?

In any case this acid plays a very important rôle in vegetation. It is by means of it that water attacks solid rocks, sand, clay, etc., and extracts from these inert substances the fertilizing principles which are assimilated by the soil and which improve it. Water, charged with carbonic acid, carries with it in penetrating the soil the instrument whereby valuable substances are disengaged from it, such as potash and phosphoric acid, which would not be otherwise found either in the water itself or in the fertilizer applied.

It is objected that carbonic acid is formed in sufficient quantities in the soil by means of the slow combustion of organic matter, owing to the presence of the oxygen, of which I have already spoken. This objection might have some reason in regard to soils which are very rich in humus, but would not hold when applied to poor soils which contain but little organic matter; and I am inclined to believe that the carbonic acid supplied by irrigation water is useful in most cases.

Solid matter in suspension in water.—There now remains to us the task of examining water from this last point of view, as to the solid particles minutely divided which they hold in suspension and bring along in their course. The quantity of such drift matter is very variable. The quantities of this sediment brought by impetuous torrents rushing down from the mountains is almost unlimited. Pebbles, gravel, and sand are successively deposited in proportion as the swiftness of the stream is diminished, but in the calmest rivers, flowing through the lower valleys, only impalpable matter troubles the transparency of the water. We are at present considering only the ooze or mud, the quantity of which is of course increased in time of floods and diminished at low water.

It has been observed that Alpine rivers, such as the Var and Durance, are muddier in fine weather than in the winter time, owing to the melting of the snow in the most elevated parts of their course; while such rivers as the Seine and Saone, only flowing through plains or low mountain ranges, are, on the contrary, muddier in winter than in summer.

The mud deposited by rivers is a mixture of impalpable sand, clay, carbonate of lime, and other minerals, dissolved into very fine particles; and finally of organic substances nearly always azotic in character. The quantity of these substances varies in different rivers, and even in the same rivers from one day to another. It always happens, however, that the mud deposited by them is analogous to that of the most fertile soils and contains nearly all the mineral elements which are useful to vegetation.

Azote (nitrogen) contained in mud.—The mud held in suspension in irrigation waters and supplied by them to the soil can not fail to add to its fertility. Attention is here directed to an experiment conducted by M. Hervé Mangon on the muds of the rivers Durance, Var, Loire, Marne, and Seine, where we see that even the poorest mud of the rivers Seine and Marne is as rich in nitrogen as stable compost and should be considered as a fertilizer. The Alpine rivers are less rich in nitrogen, but they, also, by means of repeated irrigation, add much of this valuable component of the soil.

Take, for instance, the experiment made on a hectare of land by means of the water of the river Durance and with the quantity of water heretofore made use of in France, viz, 15,532 cubic meters during the six summer months. It is demonstrated in this experiment that the water contains on an average 1.46 kilograms of matter in suspension to every cubic meter, which gives, for the total weight of mud deposited on the piece of land, 23,706 kilograms, which contains from 16 to 29 kilograms of azote, and this is equivalent to from 4,000 to 7,000 kilograms of manure.

AGRICULTURAL MANAGEMENT OF WATER.

[Chapter II, pp. 30-35.]

SURFACE AND SUBTERRANEAN WATER.

Use of rain water.—The cultivator ought generally to occupy himself in collecting and conducting to the most suitable places the rain water, which, when the soil is neither too dry nor permeable, flows off over its surface or runs into ditches or channels. Unless this water be collected in reservoirs it could not be used to irrigate arable lands, which only must be irrigated when there is an insufficiency of rain. But the permanent prairies are benefited, at all times and whatever the climate may be, by slight irrigations as well as those of a more copious character. A meadow, then, in some bend of the land, may be formed by a simple management of the rain supply.

Much depends, however, on the nature of the soil. If it be permeable to a great depth the absorption will be so great that the drains provided for it will be insufficient. If the soil, on the contrary, be very impermeable, the water will run along on the surface of the soil, washing and impoverishing it, and becoming in the process itself more fertilizing. The effects are, moreover, as intermittent as the rain is.

Indeed, in a permeable soil lying on one which is less so, the first rains succeeding a drought will be entirely absorbed. But very soon, if the weather continues rainy, the soil becomes completely saturated, and then, little by little, the water will begin to flow off wherever it meets with the least resistance. Let a ditch be dug in such soil, and at the end of each rainy spell the water will begin to ooze from the sides of the ditch, making a small water course which will fill the bottom of the ditch. In such a locality, in ordinary seasons and under the above conditions, a flow of water can be obtained which if not regular is at least continuous during from five to six months.

The trenches with which the roads are lined and which inclose the fields are generally utilized to receive and conduct the water, but it would be a good plan where one owns the land, in order to collect as much water as possible, to make a ditch beginning below the whole space from which the water is to be collected, not departing much from the level of the soil, but preserving at the same time a sufficient slope to allow the water to flow off freely (3 or even 5 meters per meter if possible). This ditch is often composed of two branches inclined in different directions, starting from two opposite points and uniting at their lower extremities to form the central irrigation channel of the soil to be irrigated. All the other drains stretching over the whole extent of ground to be irrigated lead into this principal ditch.

Use of drainage waters.—This water might be more usefully employed than it is at present. It is usually the custom to conduct the water from the drains, after making use of it in irrigation, into the nearest stream of water, ravine, or ditch. In making a study of drainage one ought first to see if it would not be possible, in disposing of the collecting drains and prolonging them at need, to concentrate all this water in some spot in the lower part of the property to be irrigated. Water thus collected may be used for watering gardens, by gathering it into a reservoir, or it can be utilized in the formation of a permanent meadow, the extent of which would be determined according to soil and climate, and would consist of from 3 to 5 per cent of all the land drained. This, although a small one, is still an advantage.

Use of springs.—The water furnished by springs is often used for irrigating purposes. When there is enough water to supply a stream of water at all seasons it can be used in summer for all kinds of culture and can be applied successively on different sections of ground or be preserved in a reservoir, to be used at convenient times. The waters of several springs, each having a little water but not enough to produce a flowing stream, may be joined together, and so become useful. As to springs of small size, they are especially applicable to the irrigation of prairies, and always below their point of emergence a meadow may be created, with an extent proportionate to the quantity of water.

Location of springs.—The supply of water from springs can often be increased by artificial means. It even happens that a spring is discovered in places where the soil is observed to be always wet, or where sedges, willows, or other plants usually growing in swamps are found; in places where a constant oozing of water seems to be going on, or even in a pond whose water never dries up, but does not flow off either. The work necessary to locate a spring consists in clearing the natural channels which carry off the water of the sand, gravel, trash, and other obstructions; in enlarging these channels a little when they are formed of crevices in the rock which water can not wear away; in obliterating, by means of puddled clay, concrete, or cement, the cracks, the permeable sides of which absorb the spring water in part; and, finally, in

combining the small streamlets springing from various sources into one concentrated stream. But the nature of the soil, the disposition of the different strata and mineral substances, the configuration of the land, and the position of the springs may vary infinitely; and for that reason it is impossible to give any positive rules for the location of springs. A provisional channel for leading off the water, so as to work with more ease in a comparatively dry place, is usually provided, but the best way to do this must generally be left to the judgment of the engineer in charge.

When water is observed to be oozing out at the foot of or on the slope of a hillside, more particularly in a little circular valley, the spring is usually located by means of a cut having less inclination than the soil itself, and directed as if with the intention of penetrating the hillside. When the cut is very deep a gallery in the mountain is sometimes reached. In rocks easily worked, and at the same time sustaining themselves without caving in, as chalk, for instance, the piercing of a gallery is not very expensive. These galleries are usually from 0.8 to 1 meter in width and are 1.8 to 2 meters in height, so that the workmen can perform their labor conveniently. When the soil is of a crumbling character and needs to be shored up as the laborer advances, or when the rock is hard and can not be broken up except by blasting, the operation belongs more especially to mining, and becomes of so technical a character as to require special management and to be apparently out of reach of the ordinary agriculturist. Works of this sort are oftenest undertaken in France in order to locate mineral springs celebrated for their therapeutic virtues or those whose water furnishes cities with drinking water rather than for irrigation purposes. Many instances are cited, however, where galleries were hollowed out in looking for water for irrigation. The Moors of Spain and the Persians have thus created little streams, which, some of them, are in use to this day.

In a soil that is nearly flat, or, in other words, in a situation where water can only reach the surface by rising vertically, the vegetal soil must first be removed, and then all the mellow soil through the whole extent of which these oozings occur. The level of the water is lowered as much as possible in these excavations, either by pumping it out or by means of trenches. This done, time must be allowed for the water to settle and become clear, when it will be observed to surge or bubble up in certain places from the bottom, which bubbling is seen much more easily on account of the grains of sand moving up and down; in the absence of the sand light substances, such as small chips, may be thrown in so as to render the motion more noticeable. The position of one of these bubbling points having been determined upon, a little pump well must be made, using a barrel with both heads knocked out for the sides, and this must be sunk above the bubbling point already alluded to. But an ordinary barrel not being sufficiently strong, sections of large trees hollowed out were formerly used for the purpose.

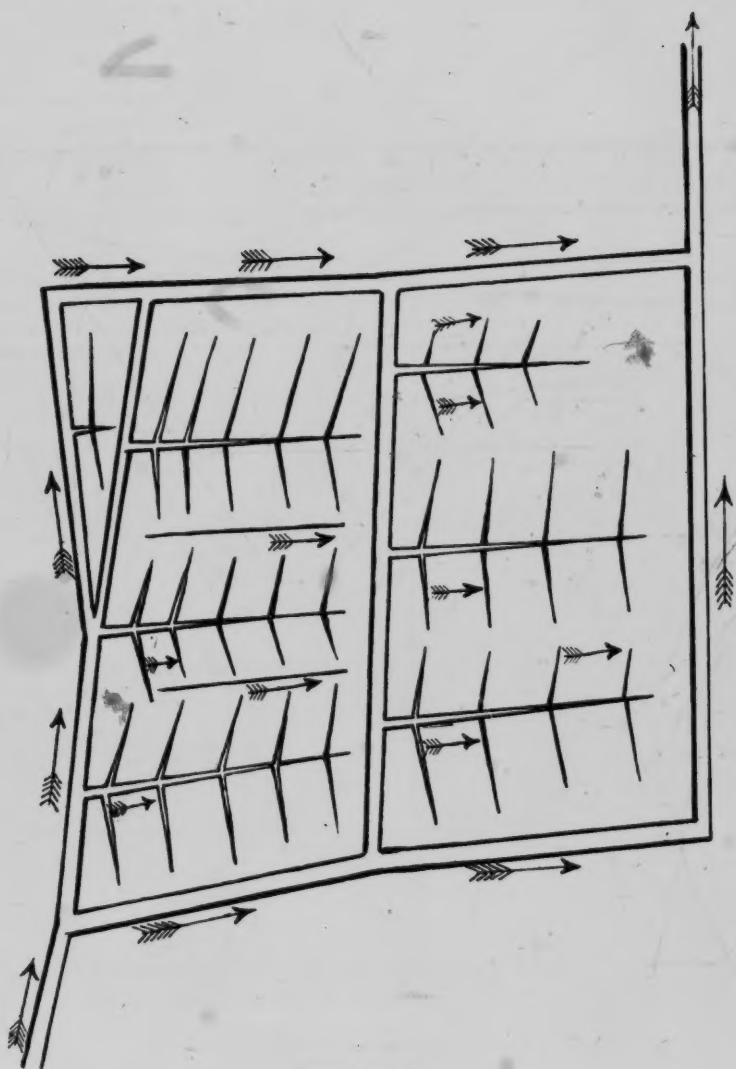
It would be better to use casks with strong staves, made of alder or oak, solidly surrounded by iron hoops, in the form of a truncated cone, which causes the hoops to be tighter. At present large pipes made of compressed concrete, especially used in building aqueducts and culverts, might be used. In every case, the pipe being vertically disposed immediately over the spring, it is sunk into the soil until the upper part sinks below the level where the definite flow of water commences. It is sunk by dredging the inside of the cylinder and directly under its outer walls, at the same time striking it on top with a mallet or putting

a weight on it. An iron kettle, the handle of which can be lengthened by fastening it to the end of a stick, will be sufficient to do the necessary dredging. The cask being correctly in place and the interior cleaned out as well as possible, a channel is made at the top of the cylinder for the water to run out at, and the clayey soil is rammed closely all around the cask or well. If this bubbling process is observed in several places the same process is to be gone through with for each place, and afterward the water coming from each one of these well pumps can be joined into one central ditch. A little basin formed of masonry, or even simply formed of planks, might make the reservoir from which the several ditches flow, and the rest of the excavation might be filled up again. Such is the method frequently made use of in Piedmont, in Lombardy, and in some parts of France.

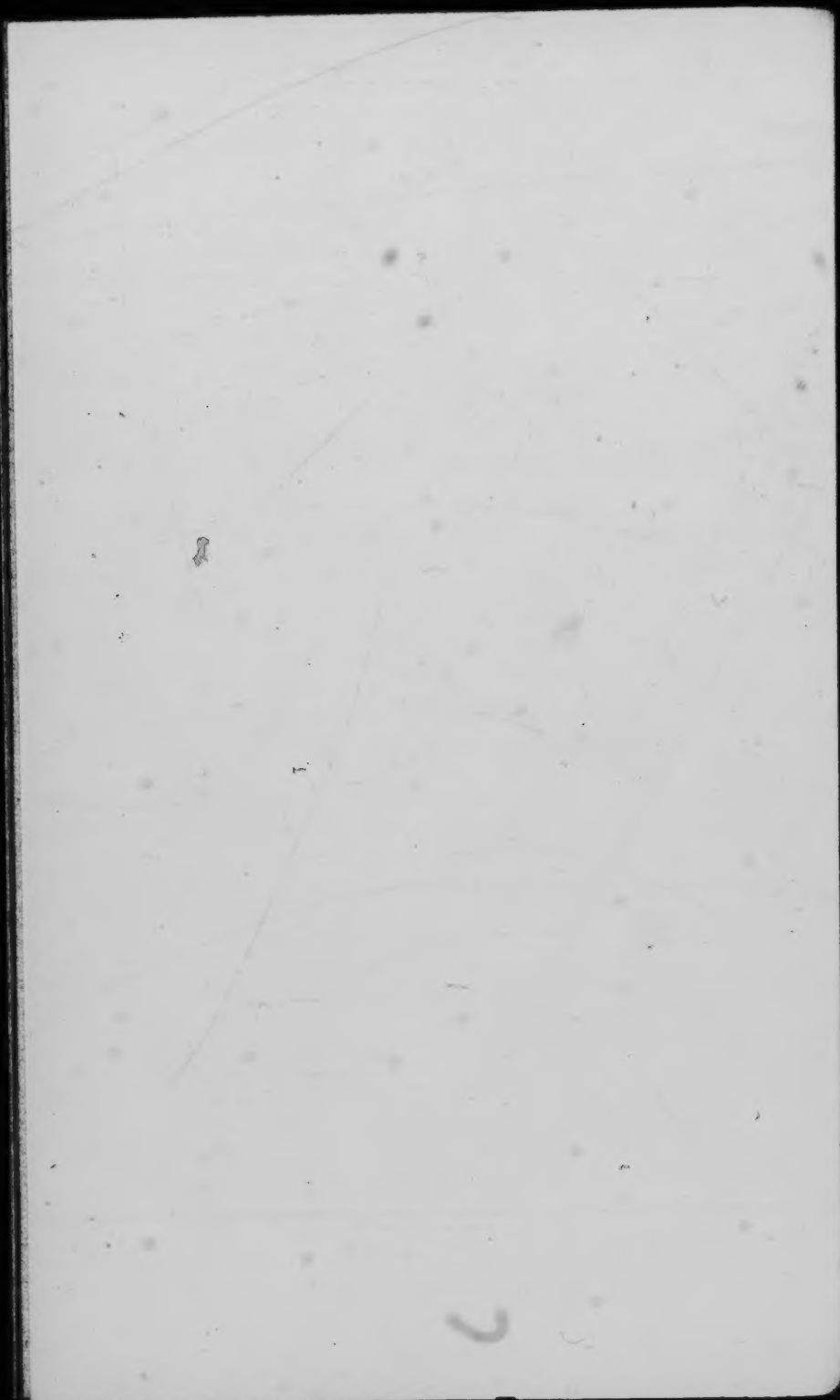
In other places, instead of casks being sunk which are all in one piece, masonry or stonework is made use of; but this is less convenient, particularly when the work has to be done while the water is there. Springs ought always to be covered with flagstones, as much to keep out the falling leaves and other débris as to prevent the growth of aquatic plants, the latter hardly ever growing in the dark. A little shed might be made inclosing the spring and its dependencies in one close covered chamber, but where the water is only to be used for irrigation purposes this extra expense is usually dispensed with.*

Employment of subterranean conduits for the water of springs.—To collect the water of a given number of springs and to conduct it to the nearest irrigation ditch, numerous kinds of canalization are used. The best way to collect several streamlets near their place of origin consists in forming little channels of masonry, large enough to hold the water without its overflowing. These little channels can either be covered by stones or embankments of earth. Sometimes these little gutters can be joined into a small basin, from whence the water flows directly into a large central ditch, as has already been said; but oftener the springs being sometimes at some distance from the soil to be irrigated it might result in too great a loss from evaporation and infiltration, to say nothing of the filling up with leaves and débris, if only a simple ditch were used. In such a case the various conduits can be directed into one "regard" or flush-box—sort of well pump—in cemented masonry and covered with a movable flagstone. From this "regard" flush-box would start an earthenware pipe, the origin of which would be at a level a little lower than the place of entry for the water; for this pipe being likely to be often full of water, a slight obstruction should be placed above orifice to prevent too full a flow. Earthenware pipes are still in use, as formerly, but care ought to be taken to keep their joints well cemented. It is so difficult to lay these pipes that it is necessary to employ only such laborers as are especially familiar with this kind of work. These conduits, however desirable in other respects, lack elasticity, and the least piling up of the soil may cause them to be ruptured. And then, besides, the small crack would allow a little rootlet to enter, and a network of roots being developed from this small beginning would soon completely fill up the inside of the channel. Engorgements and repairs are more rare in earthenware pipes, and, when motives of economy do not forbid, it would be best to make the pipes of metal. The cement manufacturers of Porte-de-France, near Grenoble, undertake to make conducting pipes of cement, which

* Indications relative to (captage) location of springs and some examples of constructions raised over springs may be found in "L'Encyclopédie des Travaux Publics, Distributions d'Eau." Bechmann, No. 154.



SPIKE CHANNELS.



they build in the trenches where they are to be used. Such conduits, except for their small diameters, are more economical than those made of metal; these last rust in the long run, and their defect is the want of elasticity. With that exception, however, they are more durable than those made of metal, which rust after awhile, and offer more resistance than those made of earthenware, which have much thinner walls. To sum up—in many instances very good results have been obtained from their use in various places.

Ordinary wells or bored wells.—There is hardly any locality where, in digging a well, one or several levels of water can not be found, but it is only where the water appears at a depth of from 4 to 5 meters, for instance, that it can be used to advantage for irrigation purposes.

This state of things especially prevails in all plains forming the great river bottoms. There, under a varying thickness of vegetal soil or of mud—more rarely of peat (modern alluvium)—a deposit of gravel is constantly encountered (ancient alluvium), at the base of which is a sheet of water generally abundant, proceeding from the neighboring heights and making its way to the river. Under such conditions it is often profitable to dig wells and extract the water from them, but such water is particularly adapted for gardens, kitchen-gardens, etc.

As to artesian wells, their use in agriculture is much more restricted. This is owing, first, to the fact that the boring of such wells is very expensive, and, in the second place, that their success depends very much upon other contingent circumstances, except in the regions where experiments have already been made or where the existence of a sheet of water has been proven beyond a doubt. Everybody knows of the services rendered by artesian wells in Algeria, in the region of the Sahara.

The results of these borings are particularly favorable when the water gushes out itself at the orifice of the bore. But it sometimes happens, also, that the water only rises to a certain level below the surface of the soil; if this level is not very deep, the work done can still be utilized by the aid of a pump.

DISTINCTION TO BE MADE ACCORDING TO CLIMATE.

[Pp. 19-23.]

Advantages of irrigation in the cultivable lands of southern countries.—It is only in southern countries that irrigation can be successfully employed in all kinds of culture. In the splendid region of the Mediterranean, where the olive is the principal production, notably occupied by Italy, Spain, Algeria, and ten departments of France, the frequency and length of droughts, the persistent heat, and enormous amount of evaporation consequent thereon, make irrigation an imperative necessity in these countries. Some kinds of arborescent vegetations, among which the vine occupies an exceptional place, are the only ones which possess to a certain degree, and in virtue of the vigor and length of their roots, the power to seek at a great distance below the surface for the water which is indispensable to their growth. With the exception, however, of these arborescent species, and in localities where irrigation can not be made use of, in these hot climates only arid land scantily covered with poor crops is to be found. But let water be freely applied in these same localities, (the sun will do the rest), and the scene changes

as if by enchantment. A luxuriant vegetation will be sure to remunerate largely both the culture employed in rendering the soil fit for irrigation and the additional labor employed upon it annually.

In northern countries irrigation is especially applied to prairies.—Beyond the limits of the olive region the expense of irrigating is the same, while the advantages derived from it, considered as a means of increasing the water supply, go on diminishing as one advances toward the North. In southern countries, indeed, irrigation is practiced during six months of the year. Moreover, the need of irrigation would only be felt during much shorter periods and at irregular intervals, and there are even certain years during which the amount of water given to arable lands in excess of the natural rainfall would be injurious instead of being beneficial. Thus, in such localities as northern and central France, England, Germany, and Belgium irrigation has been compelled to be confined to special applications and to prairies. Such herbaceous vegetation as is produced on this kind of land accommodates itself more easily than any other to an almost continuous humidity, and even when the water is not needed to moisten the soil, it serves to increase its fertility. Such ground as would otherwise be almost unproductive might be converted into prairies by the application of sufficient quantities of water. In countries rather cold than warm, the herbaceous growth will receive almost as much benefit from irrigation as will the ordinary products of more southern countries, but in a different way.

Can the irrigation of other than meadow lands be successfully carried on except in southern countries?—The question as to whether the methods of irrigation practiced in southern locations can be made use of in more northern climates does not seem to be urgent just now in France, since there is a considerable amount of ordinary dry meadow or pasture land which is easily capable of being improved. All these lands can easily be converted into prairies; land which is either too steep, too wet, or too poor to be advantageously cultivated with the plow; lands which are liable to be flooded, the crops of which are periodically injured by rivers. These lands can be made prairies by first subjecting to a correct system of irrigation, and there will be much work of this kind to be done in France for a long time to come. It seems probable that if canals were constructed in other places as has been done in Provence, Languedoc, and Roussillon, the same methods would be just as successful as they have been in these localities.

The economic solution of this question, then, depends not only on climate, but on the nature of the soil, its configuration on commercial outlets—in fine, on the aggregate of the whole agricultural and industrial régime established in each locality.

The successful system of kitchen gardening adopted in and around Paris shows that, even in the climate there existing, an abundance of water applied to the soil will aid considerable quantities of vegetables, etc., such as lucern, clover, beets, etc., which would, without irrigation, be totally unproductive. This is why Belgium, Flanders, Normandy, and even the coast of Brittany, other things being equal, exceed in fertility any of the central parts of France. This fact is evidently due to the nature of the soil. The Cretaceous or transition soils of Flanders and Normandy are also found in some parts of France. That superficial stratum of mud, anciently called loess, covering some parts of the northern departments of France, is not superior in quality to certain alluvial deposits found in various other parts of the country. The difference in the crops is, then, largely due to climatic influences.

On the one hand an even humidity prevails, permitting the continued

growth of beets during the hottest summer months, while on the other hand periods of excessive humidity occur, followed by long droughts, the heat and water arriving simultaneously only in exceptional cases. Flax, which gives such remarkable results when cultivated in northern localities, is extremely difficult to cultivate in the central portions of France. It is owing to the never-ceasing humidity of the northern maritime climates that they support a vigorous herbaceous growth, where as in climates where intermittent droughts prevail the growth of flax, especially, is at times almost entirely arrested, when it withers, its stalks turn yellow, and a product appears which is not only less abundant, but which is *échaudé* or scalded, and the best of which is of very inferior quality.

If irrigation could be made use of during times of heat and drought, a modification of climate might take place and many things be cultivated which can not now be produced. Let us observe that in the Mediterranean provinces, where irrigation has been tried with great success, the temperatures found there do not differ from those of other localities as much as is generally supposed. What distinguishes the climates of the northern from the southern parts of France is that, while on the one hand the winter is long and the summer is short, on the other hand an exactly different state of things exists. It is during the summer, though, that plants attain their greatest development and ripen their fruits. It is, therefore, in such places, in situations where high temperatures are maintained only for a short time, that full advantage of the short duration of the heat ought to be realized by bringing irrigation to its aid.

Irrigation would not, however, remedy the too great abundance of rain at some seasons, or that other scourge, in countries where the plains are far from the sea, the dry, cold wind, which arrests all vegetation by cooling the ground by evaporation, and this evaporation is greatest when the earth is saturated with water.

In fine, outside of the Mediterranean region, prairies, which can be formed anywhere that water can be carried, give generally a larger net profit than any other use to which the soil can be put. But it is probable that, in many locations not naturally disposed for prairies, arable lands, which can be easily watered when necessary and when subjected to appropriate culture, will give results equally satisfactory or even superior. A large portion of the land ought, however, always to be formed into prairies.

INTERMITTENT IRRIGATION.

[Pp. 23-26.]

Irrigation should be intermittent.—If water be indispensable to vegetation, the introduction of atmospheric air into the interstices of the vegetal soil is not less necessary to all cultivated plants. The oxygen contained in the air seems to be one of the essential agents by the action of which the nourishing principles of vegetation are elaborated in the bosom of the soil. A piece of ground constantly saturated with water is a marsh and is only capable of producing rushes, sedges, shave-grass, and other plants peculiar to humid or inundated lands. As to the plants which are of ordinary cultivation, they will languish, wither, and finally die if the soil in which they are grown is deprived

for too long a time of the intimate contact of the atmosphere. Thus it follows that irrigation should continue no longer than during the time strictly necessary to moisten the soil sufficiently,* after which that water which is already there will from various causes gradually disappear, and it is only when moisture is again absolutely needed that it should be again applied. The frequency of irrigation must be regulated in proportion to the heat and dryness of the climate and the permeability of the soil. The special need of each plant should be taken into consideration.

Organization of intermittent irrigation.—When a proprietor has complete control of the waters of a stream or canal by means of which his land can be irrigated, he divides this land into fields or parcels and establishes a network of trenches, arranged so that the water can be conveyed to each one of these parcels at will, and they can then be irrigated, separately or successively, by directing the water to those points, one after another, which would seem to need it most.

In cases where the same water supply serves a great number of property-holders, an association or syndicate is formed of those who are the interested parties. The days and hours during which each one has the right to use the water is determined by rule. A rural guard or even an especial employé is charged with watching the execution of this regulation and even, in convenient times, attending to the distributing water gates.

In the plain of Blidah, for instance, there are several canals of distribution with a total stretch of about 30 kilometers (18.58 miles). All along the route of these canals are placed at the commencement of each particular land claim a lateral water gate or sluice leading into an irrigation channel and another water gate serving to bar the canal immediately below the first. The irrigations occur twice a week, one set at night and the other during the day. Each proprietor has a right to the use of the water for a number of hours or minutes, according to the size of his claim. The water starting from a reservoir above and divided into the several canals, runs through the whole length of each canal until it reaches the lowest extremity. The time required to do this is deducted from the time of irrigation. It is the proprietor situated farthest from the starting point that commences to irrigate. When the time allotted to him is at an end, the proprietor immediately above him shuts off the water by means of his water gate and waters his land in his turn. The work progresses in this way, going backwards, to the place where the canal commences, at its highest point, and beginning again in the same way.†

Evacuation of superfluous water.—When an irrigation comes to an end, it is expedient that the surface water shall sink into the soil as promptly as possible, and that after entering the soil it shall penetrate more deeply, and thus cause the suction as soon as possible, which permits the air to penetrate with it to the roots of the plants to be benefited. If there be places where the water might become stagnant these places will be swampy and the vegetation there will inevitably suffer. Thus irrigation should consist not only in conducting the water and distributing it over a certain area, but also in making that area healthy, by providing a way for the superfluous water to run off promptly when irrigation is no longer necessary. This is done by means of ditches of drainage, of salubrity, or of evacuation, so called, either by carrying

*Except in certain irrigations of prairies during winter.

†Information taken from an account of the culture of the orange in Algeria, by M. Chas. Joly.

back the water to a lower point of the same canal which brought it in the first place or in a special canal or to some place where it can run off conveniently. It is often necessary to prepare the soil beforehand. It is only in exceptional cases, where the soil is of excessive permeability or where the irrigation is so managed as to be entirely absorbed before attaining the extreme limits of the soil to be irrigated, that this plan can be neglected. It is through ignorance of this fundamental principle that some persons only succeed in growing rushes where they had intended to improve a meadow or piece of ground by furnishing it with water.

Influence of the permeability of the soil.—In general, whether irrigation has been used or not, the most fertile soils are those which are permeable to a certain depth—0.50 to 1 meter, for instance—and more or less retentive in character at greater depths. This is more important still in case of irrigation. If the subsoil is composed, to a depth of several meters, only of coarse sand, gravel, or other materials which allow the water to pass through it like a sieve, drought is to be feared; besides an enormous quantity of water would be needed to irrigate such lands. If, on the contrary, immediately below the surface strata, whether in grass or under cultivation, only a subsoil is found which is almost impermeable, the space for the roots becomes too restricted, drainage can be only imperfectly carried on, the quantity of water retained after irrigation is too small, and the vegetal soil passes rapidly from a state of inundation to one of extreme dryness. This dryness is also increased by evaporation, which causes too a chilling of the soil unfavorable to vegetation. If, instead, the mellow strata be deeper, a greater quantity of water can be held in reserve, the soil having received more; after the water has ceased to arrive the plane of the water is soon lowered, and the benefit of the introduction of atmospheric air immediately makes itself felt in the space occupied by the roots. The water is not, however, exhausted. In proportion as it begins to disappear near the surface; that of the subsoil begins to rise by capillarity, and maintains a sufficient amount of moisture for quite a long time.

Previous plowing or digging up of the lands to be afterward irrigated.—The preceding considerations explain the fact, already many times proven, that digging or plowing up the soil to a depth of from 40 to 80 centimeters before commencing to irrigate is generally a remunerative operation, whether for the establishment of fields, gardens, or prairies.

IRRIGATION OF PLANTS USUALLY CULTIVATED.

[Chapters III and V. Extracts from pp. 95-189-4-193-4499-202-4-5-6-7-8.]

The cereals.—The cereals are among the number of those plants which only admit of a moderate foliaceous development, which transpire but little, and which require an abundant production of a grain sensibly dry. It might then be supposed that they would need a relatively small amount of water. This supposition is borne out by the observation which teaches that cereals—wheat and barley more particularly—while preferring a fresh and moist soil to any other, can better withstand too much heat than an excess of humidity. It is generally the custom to carefully avoid watering this sort of plants during the time the ear is developing itself and coming out of its sheath, as well as in the efflorescent stage. Corn is the principal cereal cultivated

in southern countries, where irrigation is held in esteem. It has been found there that an almost unlimited supply of water can be given during the period of the first herbaceous vegetation—which takes place from the time the seed is sown to the formation of the ear. In countries, too, where it is customary to irrigate in winter, the corn is watered soon after it is sown in the autumn. By these irrigations the fertilizing principles are laid up in the soil, of which they will avail themselves at a later period. They moderate the temperature of the soil during the winter, advance vegetation, and increase the suckers. Later, if the weather be dry, the corn receives another irrigation between the time of the first appearance of the ear out of its sheath and the time of efflorescence. Finally, it is again watered once or twice between the time of efflorescence and the harvest.

In the south of France corn is not watered in the winter time. If irrigated it would be too far advanced, and would be more susceptible on this account to the severe effects of the cold spells always to be guarded against at the commencement of spring. During the other seasons only a limited number of irrigations must be given to the corn, the water being reserved for the more remunerative cultures. Corn is even planted in nonirrigable lands. In this last case, when the ground has been deeply worked and mellowed for the preceding crop, corn, not being affected by drought, is able, without notable accident, to pass successfully through all the phases of its development. It will, however, yield only a product of medium quality as to grain, and of mean development as to fodder (straw). Such a crop is not lucrative, and so corn has been replaced by other kinds of culture—especially arborescent vegetations and the vine—in many departments of France. This is not to be regretted, as there is sufficient land which is still devoted to cereals, and the means of transport for the same are abundant. It is well, however, to find that, at need, crops can be raised in the south of France equal to those produced in the lands best adapted to the culture of cereals; but this can not be accomplished without the aid of irrigation.

It has been claimed that when corn is irrigated the supply of fodder (straw) is increased at the expense of the grain. I think that there is, however, a great deal of exaggeration in this assertion, or, at least, that it only applies in lands where the soil is too light or too poor for the corn. In slightly clayey soils which are also provided, either by nature or by repeated applications of a fertilizer, with the mineral elements necessary for the formation of wheat, irrigation while increasing the quantity of the grain also increases the quantity of the straw in still greater proportions, and it is because the volume of straw is so greatly increased that the quantity of grain appears to be diminished.

Grass prairies.—In the southern departments of France certain portions of the irrigable soils are devoted to grass prairies. The ray-grass of Italy, the tall *félugue* (a sort of grass) grow on them, and sometimes, also, the white clover, and "*lupulines*," besides other grasses. The irrigations indispensable in these climates to the preservation of these prairies are made use of, except during very rainy seasons, from the end of April to the end of September, and renewed as much oftener as the soil when of a less clayey nature dries up more quickly. The intervals between the irrigations should be from 5 days at the least to 18 days at the most; generally 10 days are allowed to elapse between the irrigations. These prairies, supplied each year with fertilizing matter, will furnish as many as three cuttings of forage. The water, generally abundant in winter, is sometimes not applied to them as it ought to

be according to the rules already laid down for the irrigations of such prairies.

Lucerne (or alfalfa).—Although it objects to stagnant water and impermeable soils, lucerne is one of the plants which draws the greatest profit from a soil maintained in a constantly fresh condition. There is no doubt that in all parts of France where it succeeds naturally its products might be notably augmented if subjected to such irrigations as those used in the maintenance of permanent prairies. Precautions would have to be taken, however, based on the fact that leguminous plants do not bear prolonged submersion as well as the plants of the grass tribe. The duration of the irrigation should be abridged, and should only be applied to land which can be drained to a great depth, for the lucerne is a plant of very deep vegetation. It could not live where the water was stagnant in the subterranean space occupied by its roots.

Though successfully cultivated all over France, it is nevertheless a plant of southern growth, and it is only when cultivated in a warm country, with irrigation, and in deep soils, that its full value can be appreciated. In the south they do not hesitate to irrigate it frequently. This plant would take the place of the grass-prairies, and advantageously, if its culture were not forcibly restrained by the limited duration of its growth, and if, on the other hand, the grasses were not calculated to prosper in soils of little depth, such as those in which sheets of subterranean water are found; such soils as would not be favorable to the cultivation of lucerne.

When to favorable conditions as to situation are added a fertilizing agent and intelligent care, the lucerne in the south gives four or five cuttings during the year. Irrigation is resorted to from one to four times between two cuttings—in other words, from once a week to once a month, according to the greater or less time during which the soil is capable of retaining its moisture. From 2,500 to 3,000 kilograms are obtained per hectare and per cut, making for the year 10,000 to 12,000 and even as much as 15,000 kilograms of dry forage per hectare, or its equivalent in green forage.

Clover.—If the lucerne is a plant for warm countries, the clover is, on the contrary, the one specially adapted to the most southern portions of the temperate zone. An atmosphere which is habitually moist seems to be one of its principal necessities—and it is a source of riches for Scotland, England, and for the northwestern provinces. In the central part of France it no longer yields a crop comparable with the nature of the soil; as to the region of the Mediterranean, it is very little cultivated (clover), even in irrigable lands. It must be recollected, however, that too great dryness of the soil in that region is injurious to clover, and if it were possible to obtain in the middle zone of France the same means of irrigation already available in the southern zone, it would be interesting to make experiments on the clover especially, as the plant which would be best adapted for such experiment.

Hemp.—Hemp is very extensively cultivated in countries where irrigation is made use of. By irrigation its cultivation is rendered really productive and becomes a rich specialty, particularly in the south of France and of Italy. Hemp is cultivated in irrigated countries exactly in the same way as in other situations—that is—the land is divided into plats separated into paths, which are 30 centimeters in width, so as to allow room for working the plants, and specially for pulling up the male stalks. In order to irrigate thoroughly the plats must only be about 1 meter in width. The walks or paths must be thrown up with

the hoe to the depth of several centimeters, and the earth thus dug up will serve to cover up the seed afterwards. In these paths, a little later, the water will be made to run. Hemp loves a soil which is always fresh, and is, moreover, never placed into any but permeable soils; for this double reason it is one of the plants which require most frequent irrigations. On an average it must be watered every ten days, and sometimes even oftener. Unlike many other kinds of vegetation, the soil in which it is planted must be maintained in a state of constant freshness, if not humidity. One must not wait to irrigate again until all traces of the former irrigation have disappeared, but very light irrigations must be given very frequently. Irrigation must, however, be totally suspended sometime before the flowers make their appearance.

Flax.—Flax is to northern countries what hemp is to southern countries. Not only is the dryness of the soil prejudicial to it, but so also is the dryness of the atmosphere. Irrigation has been made use of in the Département du Nord with remarkable success. I think it very probable that generalized irrigation will be the only means of extending the flax region beyond its present limits, which limits are tolerably southern, and have not so far been passed with success.

Arborescent culture—Trees, as a general thing, are less affected by drought than the generality of vegetation of smaller dimensions, and this is explained naturally when the greater depth to which their roots descend is taken into consideration. Thus the oak, planted in the soil which furnishes the proper elements necessary for its successful growth, traverses with its powerful taproot such soils as it is difficult even for the pick to enter, and which would offer insurmountable obstacles to the penetration of the fine little plants cultivated in our fields. The vine goes deep down into such soils as contain no stagnant water in their subsoil. It is particularly partial to those situations where the subsoil is formed of calcareous rock which is split or cracked; there it insinuates its roots to the depth of several meters into the fissures filled with clayey earth, and extracts therefrom at the same time the mineral food and indispensable moisture. It is then only after persistent droughts have considerably lowered the level of the subterranean moisture that such vegetations would stand in need of irrigation. During ordinary seasons it would rather be harmful to them, for their longest roots having reached a depth where water nearly always exists, it is very necessary that at least a part of the root system of these plants should have the advantage of aëration. The fruit trees cultivated in orchards and gardens have not such a deep vegetation as those already cited, but experience demonstrates that the same remarks refer also to them. Fruit trees, indeed, can, at need, support, in the south of France, long droughts mostly during the summer, especially if no vegetables of any kind are cultivated in their shade, and if the surface of the soil is kept always mellow by tith-dressing applied often. These trees have a more regular growth and are more vigorous and productive when the soil in which they grow can be irrigated when necessary, only this must not be overdone. The subsoil must not be kept for a long time continuously saturated with water in a certain depth under the soil. It can be easily understood how much the nature and disposition of the lower strata of the soil can modify the method to be pursued. The only rules which it is possible to lay down are, that irrigation shall not be resorted to until the drought shall have already penetrated to a considerable depth, that it shall not be renewed until all the water from the last irrigation shall have completely disappeared.

Irrigation is never more serviceable than when administered a short

time before the fruit matures; then the water has time to descend to the suckers of the lowest roots. Then a little air enters the soil at the same time, and then the tree is in the best possible conditions at the time when it is about to put the finishing touches to its fruit.

The hotter and more scorching the climate the more evaporation takes place, the more the level of the moisture is rapidly lowered after a rain or an irrigation. Thus, in the north of France, fruit trees would only need to be watered in exceptional cases. On the border of the Sahara, on the contrary, no irrigation is possible unless water can be furnished by an artesian well to irrigate the date palms, which form the oases of this torrid region. In the Algerian Tell and in Spain, all the fruit trees are submitted to regular irrigation, even the vine is no exception. In the south of France irrigation is used more sparingly, and it has been noticed, moreover, that all kinds of trees are not benefited by it in the same degree.

The orange.—This tree needs a (fresh) moist soil. If the one where it is planted it does not furnish this condition, irrigation must be resorted to. In permeable soils and also in very warm climates, such as Algeria and the south of France, irrigation is kept up all the year, the plants being watered about every fifteen days during the summer and autumn, and at longer intervals and with less regularity during the winter and spring. In these countries it is only when the subsoil is compact and retains the humidity that irrigation is completely suspended during the rainy season. In those parts of France where the mildness of the climate will permit of the cultivation of the orange irrigation is hardly made use of except from June to November, and even then in moderation.

The pomegranate.—The pomegranate must also only receive a moderate amount of water, or else the fruit will be of little value, small and almost tasteless. It is remarkable that when the pomegranate is irrigated every part of it is developed simultaneously. When, on the contrary, it is not irrigated at all, the outer woody envelope often hardens and soon stops growing. Then it bursts under the pressure resulting from the swelling of the seed.

The mulberry.—The mulberry, cultivated for its leaves, ought to be watered in times of drouth, but with great circumspection. The quantity of water supplied to the soil ought to be less than will be sufficient to bring the plant and its foliage to its highest degree of development. It is known, indeed, that when mulberries have been grown in too moist a soil they produce a large and very tender leaf, but at the same time very watery and not very good for the silkworm to feed upon. In Algeria, in a warmer climate, the same tree is watered all through the winter. These irrigations, while furnishing an abundant provision of moisture to the soil, makes it at the same time more fertile and causes a precocious and vigorous start of foliage. The irrigation must be completely arrested just as soon as the leaf begins to sprout and until the fruiting and pruning seasons are over. Irrigation is then begun again, and its influence, combined with the heat reigning at this season of the year, causes new leaves and buds to push out. This practice would seem to be a rational one.

Often, in the most southern parts of France, mulberries are planted around fields or on the banks of ditches; these last serving at the same as fencing and also as channels for the distribution of water when the soil in which the trees are set is a little higher than the canal. In this case the mulberries are provided with a soil, dry enough to a certain depth, but at the same time having a subsoil which is always sufficiently moist.

Fruit trees in fields.—Fruit trees play an important rôle in the south of France, where certain kinds are cultivated on a grand scale. Irrigation is sometimes used successfully in some of these fruit cultures. Generally, however, trees which bear fruit in the spring, or at farthest in June, are very little irrigated, the earth preserving up to that time sufficient moisture. Trees which only bear fruit in autumn, must necessarily be irrigated from the commencement of the month of June and nearly up to the time of maturity—such as peaches, autumn pears, and apples. It must be remembered that irrigation is to be avoided as much as possible for all kinds of fruit trees during the flowering season.

The almond is not watered at all in France, nor are the fig trees, except one or two late varieties, which are only found in gardens.

The jujube.—The jujube tree, which bears fruit very late, only gives satisfactory results when irrigated.

The olive.—The olive, which is so valuable in all the countries surrounding the Mediterranean Sea, has a marvelous power of resistance to droughts. It even avoids moist lands, and nowhere gives fuller returns than when growing on hillsides in a permeable calcareous subsoil. It is undoubtedly true that irrigation sensibly increases the products of these trees in the climate of Provence, but it must be used with extreme caution. Before the end of the last century trials were made in regard to irrigation as applied to the olive, on the banks of the canal of Boisgelin, between Arles and Aix, and the results appear to have been marvelous in regard to abundance of production; but the terrible winter of 1789 killed the roots of the olives which had been subjected to irrigation, and it has not been resorted to since. This has not convinced me, however, that a like mortality would have been the inevitable consequence of *all* irrigation. The moderate use of water must be separated from the abuse of it and the nature of the soil must also be taken into consideration, especially that of the subsoil, as well as the periods when the irrigations are applied. Above all, there is in Provence no want of other rich cultures to utilize its soils which are irrigated, while this department is particularly fortunate in possessing such a tree as the olive, which accommodates itself readily to the driest soils and those which it would be difficult otherwise to utilize. It is certain that in countries still more southern than in Provence, where there is no danger from frosts and which are the true habitats of the olive, this tree has been subjected to irrigation at times, and great advantage has resulted therefrom, provided that the price of water was low enough. Irrigation must commence from the month of December, but always as soon as the olive crop has been gathered. No irrigation must be made use of during the time of efflorescence, which occurs in the month of April, after which water is supplied every time the soil becomes too dry. It is especially necessary to irrigate in September, so as to increase thereby the size of the fruit. Finally, irrigation must entirely cease a little while before the olives mature.

The vine.—Nearly everything said on the subject of the olive will apply equally well to the cultivation of the vine. The same resistance to drought, the same predilection for soils which preserve but small traces of humidity, if not at a great depth, the same abstention from irrigation may be observed in the culture of both vine and olive in all parts of France. The same employment of irrigation as is observed in other countries, especially in Spain (southern), prevails. Near Avignon M. Fancon has lately subjected his vines during the winter to a submersion during nearly forty days consecutively with a sheet of water of a minimum thickness of 10 centimeters above the soil; but in

view of the inequalities of the soil and of the partial absorption which might occur an average of 20 centimeters of thickness must be allowed. Not only has this plan of operation appeared to have destroyed the phylloxera, that terrible insect which attaches itself to the roots of the vines, thus putting in peril the vineyards of the South, but the vines subjected to this winter irrigation appear also to be in the most flourishing condition possible. They are vigorous and productive, but must be fertilized every year.

A definite opinion, however, can not be formed on this subject until a more prolonged season of experimentation has thrown more light on it. This submersion must be repeated every year, on account of the near neighborhood of the vines still affected by phylloxera, which have not been submerged.

The soil is divided into compartments by small earth dikes, in order that only the extent of each compartment may be flooded without the necessity of spreading the water over the whole slope of the total extent of the vineyard.

Rice plantations.—Rice is one of the water grasses, and like the reeds it is necessary for its successful vegetation that it shall always have its feet in water. Rice is irrigated especially by submersion. A permanent sheet of water 15 to 20 centimeters in thickness, incessantly renewed by a thin stream of water, is the best method of submersion. But at certain periods this supply of water must be diminished to a sheet of water only a few centimeters in thickness. In certain special accidental cases it would be well to increase this sheet to as much as a thickness of 40 centimeters.

Finally, at the time when the rice is to be worked and at the time of harvest, it must be arranged to have the soil dry, in order to facilitate these operations.

To carry out perfectly the above conditions, the land must be divided into evenly-leveled compartments. Each one of these compartments must be surrounded by dikes nearly 50 centimeters high. As the soil, before the establishment of rice plantations, has generally a certain slope, the lower end of each compartment will be found to have a different level from the upper end. If the whole ground is decidedly level, one or several hectares of extent may be allowed for each compartment; but this extent must be reduced in proportion as the original slope of the ground was more considerable, so as not to have the embankments too high, and also to avoid having too great a height between one compartment and the next. The dike separating the two compartments should be only about 50 centimeters in height, counting from the bottom of the highest one. At the highest part of the dike it must be 66 centimeters wide, which dimension is indispensable for a path of service. A stream of water must then be turned into the highest compartment. From this point the water circulates from one plat to another by means of wasteweirs arranged in the dikes, the sluices at the lowest end serving to drain off the water at will and leave the rice field dry when desired. A ditch must be dug to carry off the water after it reaches the lowest plat; that is, when the water does not run off directly into a running stream or into the sea. All these arrangements are so simple as to be easily understood, and need no further explanation.

Rice plantations can only be carried on in situations where the land is nearly horizontal or has only a very gradual slope. These conditions are often furnished by marshes or by land lying along the seashore. Land of this description, which is of very little use for other cultures,

is precisely that which would give the best results if devoted to the cultivation of rice. Those which are slightly salt are not to be avoided, for the water when continually renewed dissolves and carries off the salt as it rises from the subsoil to the surface, and it is even sometimes the means of getting rid of the salt entirely. To this freshening process is added the happy effect caused by the deposit of mud contained in the water used for irrigation, the quantity of which becomes quite considerable in course of time. Thanks to these effects it must be seen that the cultivation of rice in certain unproductive soils makes that soil capable of producing other crops afterwards.

Sometimes rice plantations are carried on one year with submersion, and the next year the soil is put into other crops, without being submerged; and both plans are found to be successful. The dikes would have to be removed the second year, of course, as they would be in the way when the ground was put in order for the other crop; they could, however, be easily rebuilt.

Sometimes a continuous stream of water is not required in cultivating rice, and only supplied during certain periods, as in other lands devoted to irrigation. If necessary, rice planting can be carried on in this way. In such cases the water is left standing for several days, when it is again administered.

This method is very inferior to that of applying a continuous stream of water, as then the rice plantation is always invaded by a great abundance of adventitious plants, and is more unhealthy than when subjected to a continual stream of water.

Rice plantations are essentially unhealthy, and are supposed to cause the prevalence of intermittent fevers, and can be prevented by no management nor hygienic conditions now known, whatever may be said to the contrary. In the mud which covers the soil myriads of insects and animalculæ are moving about. When the water is turned off the rice fields this soil dries little by little in the scorching rays of the sun. The plants with which it is strewn, the animal life, and especially the infusoria which pervades the soil, die, and cause a putrid fermentation. This is, probably, the cause of the evil.

If there were sufficient movement of the water, or if the rice could be worked and harvested under water without ever completely turning the stream, it is possible that this unwholesomeness might be overcome.

It might be found that, on lands which are alternately submitted to inundation and drought, the insalubrity might even be found to exist to a greater extent.

Quantity of water required for a rice plantation.—It has been calculated that a continual stream of water of $1\frac{1}{2}$ liters to 2 liters per second and per hectare is necessary for the establishment of a rice plantation; but there are many times when a greater quantity might be required.

IRRIGATION BY ARTESIAN WELLS IN ALGIERS.*

[Translated for the Office of Irrigation Inquiry.]

M. Daubrée has drawn attention to the notes on artesian wells in the provinces of Algiers, Oran, and Constantine, which have been published by M. L. Ville, general inspector of mines. Besides the native wells which have existed for centuries—especially in the Sahara—to bring water and fertility to many parts of it, a great many wells have been bored by more perfect methods. It is but fair to mention the initiative taken as long ago as 1844 by M. Henri Fournel, at that time chief mining engineer, showing the utility of a chain of wells to be established between Biskra and Tougourt. Soon afterwards, in 1848, M. Dubock, mining engineer, established one in the neighborhood of Biskra, under the patronage of General Desvaux, who has not ceased to encourage in the most active manner other borings of the same nature. From that time up to 1875, 615 wells have been bored, of which 404 are in the province of Constantine, 194 in the province of Algiers, and 15 in that of Oran. These wells belong to different basins, and these basins are subdivided into other distinct basins. Thus, in the province of Constantine, the great basin of the Sahara incloses 104 wells, divided into three basins; the richest in wells is that of the Oued Bir, to which belongs the oasis of Tougourt.

Among the diverse basins of the province of Algiers is included that of the plain of Metidja, which is subdivided into 4 basins inclosing 80 bored wells.

The total length of the borings is 26,352 meters (86,456 feet). The total cost has aggregated 2,497,780 francs (\$499,558), which gives an average of 95 francs to the meter (nearly \$19). Most of these wells have been bored in old alluvial soil, in Quarternary deposits or in Tertiary beds.

Among the most interesting facts may be mentioned the increase of temperature, which in the borings of the "Grand Lac" rose to 57.50 feet; now the average increase is one to 98.4 feet. This is a very rapid increase, of which, however, there are other examples. Some of these waters are charged with saline matter.

Discussing the origin of artesian waters in the Sahara of French Algiers, M. Jachele, army chemist, stationed at Biskra, Algiers, published the following interesting statement in the "Journal de Pharmacie et de Chimie" of August 1, 1889 (page 102).

M. Paul Leroy Beaulien, in his work, "L'Algérie et la Tunisie" (page 146), says: "There is yet another work to which the French administration has applied itself with most brilliant success, and which is capable of still greater developments, and that is, the artesian wells. This work has been the means of creating oases, and may yet extend cultivation to the extreme south. A Russian publicist, M. de Tchihatchef, who has recently (1880) made Algiers a study, speaks of it with enthusiasm, and esteems highly the importance of the results which we have obtained. He writes: "Between the Chott Melghir and the town of Tougourt, a distance of about 120

* Bulletin des Séances de la Société Centrale d'Agriculture de France. (1876.) Page 464.

kilometers (78 miles), there are not less than 40 artesian wells, which is one well for every 3 kilometers; and doubtless this line of wells will be continued as far as Ouargla. At present, between Tougourt and Ouargla, a distance of 150 kilometers (93 miles), there are but 5 artesian wells.

"The Russian author estimates the number of wells bored in the province of Constantine, a subdivision of Batna, from 1856 to 1878, at not less than 155. He says: 'The number of borings for bubbling water is about 149 and for ascending water 232; the total depth bored is 18 kilometers, 626 meters (61,108 feet), and the primitive discharge of the bubbling and ascending sheets is 182,119 cubic meters every twenty-four hours, or 765,742,969 cubic meters the year.'

"These figures are sufficiently eloquent and need not be commented upon, and when it is considered that they represent the work of only twenty-two years, it can be said that if France has given Algiers nothing else but these artesian wells, they alone enable her to compare favorably with no matter what other country.

"Since the Russian author has written these lines French activity has not slackened in its exploitation for subterranean sheets of water. On the 31st of December, 1881, the number of artesian wells in the three Algerian departments was 257 bubbling and 419 ascending wells. The total depth of the borings was 27 kilometers, 837 meters (91,525 feet), 50 per cent more than the figures given by M. de Tehlatchef."

The few Europeans who have ventured into the region of the bubbling wells south of the department of Constantine have interested themselves concerning the origin of these undrinkable artesian waters. The hypothesis of an interoceanic current is now held to be untenable, as chemical analysis shows that the composition of these waters has nothing in common with sea water.

The greater part of this section of the Sahara is below the level of the sea, and being bounded on the north by the Auris Mountains has led to the general admission that the artesian waters arise from the infiltrations of rainwater in the Tell River and the high plateaus. We will examine what truth there is in this. A careful study of the artesian waters of the region of Tournegouth-Ouargla will enable us to understand—

First. That the hydrostatic level of these bubbling sheets of water is higher in proportion to the depth of the sheet.

Second. The discharge of artesian sources increases with the depth of the sheet.

Third. The quantity of salts dissolved diminishes as the depth of the sheets increases. In waters which have been analyzed up to the present time this quantity varies from 4 to 15 grams=60 to 225 grains.

Fourth. The weight and grouping of these dissolved salts do not vary much with the seasons nor with the years.

Fifth. Sulphate of lime dominates in the artesian waters, and in decreasing order the alkaline chlorides, the earthy carbonates, etc.

Sixth. All artesian waters contain nitrates, without applying to these salts the rule in paragraph 3. Sometimes there is more nitrogen found in a lower than in a higher basin, and again inversely (nitrogen in a combined state of nitric acid), but generally the proportion of combined nitric acid does not vary much in these artesian waters.

There is no current, since the waters are not all of the same composition. They are solid, located in natural superimposed reservoirs, and separated by layers of impermeable limestone.

A knowledge of this phenomena controlling these bubbling waters enables us to determine their origin, and it is not believed that they can come from the calcareous mountains to the north.

In the first place the waters of the Tertiary Algerian strata and of the fossilized limestone of the Auris Mountains mostly contain alkaline chlorides. During infiltration and passage into the Quaternary basins, they preserve these salts in dissolution; now, the proportion of chlorides which is found in artesian waters is from four to five times less than

that which exists in the waters descending from the Auris. This fact is also applicable to the carbonites. The waters of the Auris contain but few sulphates; it is true that while infiltrating into the Quarternary strata they might get charged with sulphates; but there is no reason why quantities of other dissolved salts should diminish so considerably.

In the second place, the department of Constantine and the extreme south does not contain any deposit of nitrates, nor do the waters of the high plateau on the Mediterranean side of the south side of the Auris contain nitrates, unless accidentally. These waters infiltrate themselves into the Tertiary strata and reach great depths under ground, without any contact with the air or nitrogenous matters. Therefore, the basins of the Sahara can not get so charged. If the artesian waters come from the north, how can we explain the presence in them of the combined nitric acid?

Formerly there existed at Biskra some military saltpeter works. Little hillocks, formed by the remains of ancient Arab villages, built in pise (pounded earth and shell), furnished the nitric earth; but independently of these, nitric beds alone are used here.

Everywhere where the waters produce these efflorescences by evaporation, which often spread over many miles, nitric acid in a combined state is found associated with the sulphate of lime and the alkaline chlorides. Not only do the nitrates exist in the water of the Oueds, but they are also found in the sheets of water caused by infiltration, which are not bubbling but on the surface. Such is the sheet of the Zibans, a fortune to twenty oases, which, by its influence, are covered with magnificent date-palm trees.

Returning from a mission to the Sahara in 1861, Mr. Ville, mining engineer, published the analyses of the waters collected by him between Boné, Ouargla, M'zat, and Algiers. He drew attention to the presence of the nitrates in the potable waters of the country of Mozatites. The fifth of the natural salt found in these waters is the nitrate of soda. This is remarkable and could not fail to be observed. As to the origin of this nitric acid Mr. Ville says:

The presence of these nitrates is probably owing to the electric state of the atmosphere during violent thunderstorms, which occasion the floods that fertilize the oasis of Beni-M'zat.

However, this explanation of Mr. Ville does not seem admissible for two reasons:

First. The thunderstorms of the M'zat are neither violent nor frequent enough to manufacture, with the nitrogen of the air, the composite nitrates which are found in the water. If the nitric acid is produced in the atmosphere by the electric fluid acting upon the nitrogen of the air, and upon the ozonized oxygen, it is by the vapor of the water condensed into rain, so that the acid is formed and taken into the soil. Now, in that part of the Sahara of Constantine during some years there is not more than 2 inches of rainfall, so that can not be the origin of the permanent nitrates, especially as in the Tell and the Auris the thunderstorms are more frequent than in the Sahara, and yet the waters of the Tell do not contain any nitrates.

Second. The fluvial and artesian waters of the Sahara when analyzed are found to contain the same quantity of nitric acid, no matter when the trial is made, whether during the seasons of thunderstorms or at any other time.

The waters of Oued Biskra and the Oued Bir have the same composition to-day that they had in 1861. The discharge of the sources of the

Oueds may have varied, but the proportion of the salts dissolved in the water has not changed any more than the soil from whence the waters are derived.

The presence of nitric acid in the atmosphere during thunderstorms is of little moment, but the presence of artificial saltpeter works, like those of Biskra, is a rare fact accidental in the Sahara. The presence of these nitrates is general in the waters of the south; in the waters which flow through the inhabited oases and also in the wells of the desert, far from all animal life.

We think that the clayey alluvium of Chott Melvir (the ancient sea of the Tritons), like the gypseous sand of the quaternary strata, possesses in the highest degree the property of continually setting free the nitrogen of the atmosphere, even outside of all vegetation.

Third. The presence of these nitrates in the artesian waters prove their origin. The waters come in great part from a quaternary formation.

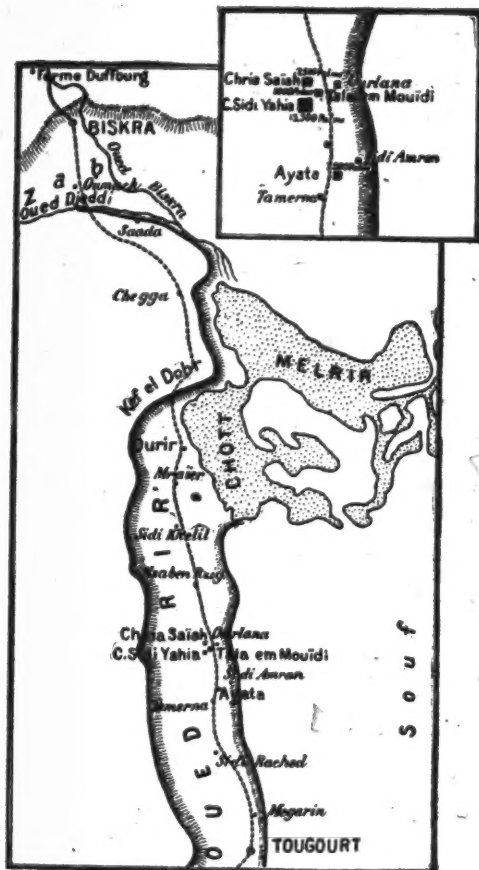
These infiltrations take place naturally at high altitude. This, during the infiltrations from the surface and in the shallow beds of the soil, shows that the water is charged with the nitrates. The dissolved salts penetrate the lower basins and when the artesian bore causes the water to recover its hydrostatic level, the nitric acid is combined in the same proportions as in the water which flows up in the original surface above.

Recently the attention of the civilized world has been called to the organization by Cardinal Lavigerie, of Algiers, of a Catholic order to aid in the suppression of the African Arab slave trade, with its terribly destructive raids, its wholesale slaughters, deportations, and sales. The headquarters of this order has been established at Biskra, on the South-Algerian borders of the Sahara. Quite a large number of affiliates are already there, and the place was consecrated in March, 1891.

The name of the spot is M'salla, which is the Arabic designation for "a place of prayer." The estate contains a plantation of palms in full bearing, and is traversed in part by a small irrigation canal, bearing its share of the precious fluid from the neighboring town to which the area is entitled. Great stretches of ground, however, are uncultivated for the want of water, and measures have already been taken for its reclamation by the creation of a further artificial supply. A well was sunk to a depth of 53 meters (over 163 feet); the water, declared to be practically inexhaustible, rises naturally to within 32 meters (105½ feet) of the mouth of the well, and is thence raised by pumps to the surface. A second well has also been dug, in order to provide temporary auxiliary resources. The militant monks will therefore be trained in the methods of Saharian culture, as well as in the use of arms. The house, occupying an area of 70 meters by 10, with the kitchens and offices in outbuildings, has the ground floor solidly built of stone instead of the sun-dried mud bricks generally used by the Arabs. The choice of Biskra for the headquarters of the order is a fortunate one, for the town, which is situated in an oasis, commands one of the principal routes of the Soudan. The town proper, is composed of one large street built of European houses, and intersected by a number of smaller streets. The oasis, which is five kilometers long and half a kilometer broad, forms a forest of 150,000 palm trees and 5,000 olive and fruit trees. The population is cosmopolitan, and includes French, Tunisians, Arabs, Moors, and Israelites.

Napoleon Ney, a French engineer ("The Proposed Trans-Saharan Railway," in *Scribner's Monthly* for November, 1891), says:

To a young civil engineer, M. Georges Rolland, belongs the credit of reawakening the idea, long dormant, of a trans-Saharan railway. M. Rolland, who had been concerned with one of the Saharian expeditions, as I have already mentioned, made the subject of a desert railway his constant study. He established in the Sahara of Constantine an excellent colony, and in the desert regions of Oued Rir, between Biskra and Tougourt, he introduced a system of irrigation that has transformed the desert into a rich and profitable oasis. The ocean of sandy desert that separates the



[From Scribner's.]

Soudan from Algeria has been cited by critics of the trans-Saharan scheme as an insurmountable obstacle. And yet no one considers the Atlantic waves as an insurmountable obstacle to the exchange of commodities between the new and the old worlds. I can say that the trans-Saharan railway will bring fertility with it. With sand and water one accomplishes wonders in Africa. The Arab proverb runs: "Plant a stick in the sand and water it, you will have a tree." The name Sahara is not always synonymous with desert. Notwithstanding the dryness of the climate, the Sahara has running water courses in summer, and subterranean lakes and artesian wells too deep for surface evaporation. In the Saharian oases, where water

reaches the surface naturally, date palms make real forests and shelter smaller vegetation that shows a grateful green against the monotonous gray of the desert. The date palm grows in the most arid soil, gypseous and even saline, sandy, and stony. The palm needs heat and water—its head in the burning sun, its feet in the water. It is the chief resource of the natives of North Africa, the king of the desert of Sahara, the tree of the Bible. The date is to the Sahara what wheat is to Europe, and rice to India and China. It is the common food of the native and his surest friend. It is the chief wealth and commodity of barter of millions of people, and is exported to every country. Its use is growing in Europe and America. When it can be used as a common fruit and not as a luxury, its value will be still more apparent. The date palm fruits in eight years after planting (and sometimes in five), and its culture is profitable. With 200 trees upon a hectare (about 2½ acres) it brings in more than 1,000 francs a year. It will be seen that it is as profitable to plant palm trees in the Sahara as grapevines upon the slopes of Algeria or in the south of France. Its fruit is slower in coming, but there is no phylloxera to be feared.

I have spoken of the subterranean sheet of water under the Sahara. The results produced by the artesian wells sunk since the French settled in Oued Rir, a series of oases south of the province of Constantine, of which the chief town is Tougourt, are nothing less than marvelous. The wells of the natives, lined with wood, last but a short time owing to the filling up of the sand, and everything dies for lack of water. For this reason some of the oases have disappeared under the sand. The natives were discouraged. "Our children are weak," said one of the chiefs. "If God, the worker of miracles, does not help us, in ten years the Oued Rir will be deserted, buried in the sand." As in the cases of the deserted cities of Central Asia, to be found on the line of the Trans-Caspian road, the Oued Rir was about to die of thirst. But the miracle was accomplished, and French engineering was about to save Oued Rir. On January 19, 1856, a memorable day, the sand-drill of the French engineer, Jus, brought forth a splendid stream of water, 4,000 liters (888 gallons) a minute, to the astonishment of the assembled natives. The Fountain of Peace was the name given to this well. The sand-drill won a greater victory and accomplished more than war for the peace of the Sahara. Since then the drilling in the Oued Rir has been continued with energy and perseverance by the military authorities under the direction of M. Jus. On October 1, 1885, there were 114 artesian wells belonging to the French and 492 belonging to the natives. Counting the few natural supplies of water, this gives a supply of 253,678 liters (56,372 gallons) of water a minute, or about 4 cubic meters (141 cubic feet) of water a second, equivalent to one-tenth of the flow of the Seine in summer, or equal to the flow of several streams large enough to give their names to departments, such as la Vilaine, le Tarn, l'Avignon, and la Dordogne.

Thanks to the success of irrigation, the oases have become fertile again. There are to-day forty-three oases in the Oued Rir, 520,000 date-palms in bearing, 140,000 palms of from one to seven years of age, and about 100,000 other fruit trees. The annual production of dates is valued at more than 2,500,000 francs. The wealth of the Oued Rir in gardens, wells, houses, etc., has increased fivefold in the thirty years that have elapsed since the first well was drilled. In seven years, 1882-1889, M. Rolland and his associates have "created" oases and three villages—at Ourir, in the north of the Oued Rir, at Sidi Yahia, and at Ayata, in the central region. They sank nine wells, which give a flow of nearly 23 cubic meters (812 cubic feet) of water a minute. About 400 hectares (988 acres) of barren land have been made fertile. They have planted the enormous number of 50,000 palm trees, of which a fourth are of a fine variety known as *deglet noir*. They have dug 90 kilometers (56 miles) of irrigating ditches and have built dwellings for the French agents, the native laborers, storehouses, etc. A distinguished French engineer, M. H. Tournel, has well said that when one sees the amazing transformation produced upon the soil of Algeria by artesian water, the thought inevitably suggests itself that the conquest of the land has been achieved by first conquering what is under the land.

FACTS AND CONDITIONS
RELATING TO
IRRIGATION
IN
VARIOUS COUNTRIES.

PREPARED BY
RICHARD J. HINTON.

IRRIGATION IN NORTH AND SOUTH AMERICA.

MEXICO.

The principal crops grown in Mexico with the assistance of irrigation are sugar, coffee, corn, wheat, oats, barley, beans, cotton, and tobacco; also oranges, bananas, and other fruits. Without irrigation, except near the coast, the yield would be very meager; with irrigation said crops are excellent, and will compare favorably with those of other countries, especially when consideration is had of the primitive agricultural implements used and the inefficient cultivation, as contrasted with that practiced elsewhere. The water supply is generally from streams, springs, and lakes. Some of the springs are large and important. One of these is on a hacienda belonging to the descendants of Cortez, in the State of Morelles, which supplies irrigation water sufficient for a fine sugar plantation.

Storage and distribution works consist of dams, intended to elevate the level of the water in streams and rivers; also large reservoirs are formed by means of massive dams, generally of stone, the water being collected during the rainy season and held for use when needed.

Each State of the Republic has its separate laws and regulations regarding the distribution of water. The duty of water per acre and the amount used per season per acre vary according to soil, climate, and plants under cultivation. Moreover, the cost of water is generally included in the rental paid for the lands, which varies exceedingly in different places, according to the circumstances attending each locality. The ownership of the water is both public and private, but generally the latter, as the water privileges, being considered of quite as much importance as the land itself, have, in many instances, been transferred or transmitted by inheritance along with the title to the land.

The following decree as to water management, approved June 5, 1888, is printed in the Consular Report on "Canals and Irrigation" (1891), issued by the State Department:

ART. 1. There shall be considered as general public highways, besides the inland roads, railways, etc., to the effects of section 22, article 72 of the constitution, the following:

The territorial seas, marshes, and lagunes situated on the seacoast; canals constructed by the Government or by means of public money; interior lakes and rivers, if navigable; whatsoever lakes and rivers situated and serving as boundary lines between the Republic and foreign nation or between two States.

ART. 2. The federal executive has the power and right to look after the aforementioned general roadways, and to regulate the private and public use thereof according to the following basis:

(1) The towns situated on the seashore or the banks of a river shall have the gratuitous use of the water necessary for all domestic purposes of its inhabitants.

(2) There shall be respected and confirmed the rights of private individuals relating to the use and profit of rivers, lakes, and canals, providing that said rights consist in lawful titles or civil prescription exceeding ten years.

(3) The concession or attestation of rights or titles to private parties on the lakes, rivers, and canals, relating to the present law, can only be made by the department of public works, excepting the case when said concession shall change the course of the rivers or canals aforementioned or should deprive of the use of their waters the inhabitants living down the stream.

(4) The rights of fishing and pearl diving on the territorial seas and the uses and profits of marshes and lagoons situated on the seashore or national vacant lands shall be regulated specially by the executive power.

ART. 3. All transgressions of law comprised in the common jurisdiction committed on interior lakes, canals, or rivers, as well as the controversies that may arise between private individuals relative to obeying the statutes issued by the department of public works, shall be submitted to the competent local jurisdiction.

A small number of wells, comparatively speaking, are in use in Mexico for irrigation purposes, the water being lifted generally by wind-mills. There are some small artesian wells along the railroad lines. Of the State of Coahuila, Consul Wæssner, of Saltillo, says that—

Water is worth a great deal more than land in this country, and the right to use it is fixed by law. There is considerable water power unused, which according to law can be acquired by denouncement. If a spring of water arises in the land of any one, the owner of the property also owns the spring. Rivers are owned and controlled by the State through which they pass. Rights and privileges to public waters are sold by the State. The system of water distribution is as follows, and is generally acquired by purchase:

A stream of permanent water is called thirty days of water, and the owners may sell the right to any one to use this water for any length of time, say, for example, one day in every month, which is called one day of water, worth very often as high as \$1,000 a day. It is an understood right between all landowners that parties owning any right or privilege in the water can pass the same to their lands through the lands of adjacent owners by means of narrow ditches.

This system often causes many difficulties, particularly when the owner of a day or two of water dies and leaves some fifteen or twenty heirs, each of whom receives his share in hours, being an equal division, under the same right, of the day or two of water inherited. The formation of artificial lakes has already awakened attention, and a foreign (American) company of capitalists agitates at present the question of making a lake with the waters of the Rio Grande, to be used for industrial and agricultural purposes. This project, however, involves difficulties arising from its international character.

In all railroads and public highways provisions are required for the passage of irrigation ditches, pipes, flumes, or other modes of conveying water. A law under date of February 14, 1856, controls and regulates the distribution and measurement of water. The unit of water is identified with a furrow, and is termed the "surco" or "selco." The metrical system was introduced in 1857, and the liter (0.26417 part of a gallon) became the legal unit of measurement. The old system is still recognized when embodied in deeds and law papers. An elaborate code of regulations—handed from the Spanish control royal instructions regulating "servitudes of water"—has been promulgated in 1754. The guiding principle, both as to land and water, of these instructions was that all such property inured in the Crown and for public use and benefit; water rights were conceded to individuals as a special favor from the Crown. The law provided that to the sovereign and to no one else appertained the right to distribute natural waters. This is still the controlling principle, of Mexican law. The character of streams and other water sources was defined as follows in 1754, and the rule still controls:

A torrent is a sporadic stream, originating from snow melting or sudden rainfall.

Rivers are public and private. In the first all enjoy equal rights; in the others some special contract or arrangement regulates use—it is usually described as having "no banks." Banks indicate in law the precise course of the flowing stream.

Concessions of water make the same an appurtenance of the land through or over which it flows.

A servitude is property pertaining to the thing. As to water, it attaches the same as service for land. Two predial estates are involved; one is entitled to use of water on another person's land, the other is recognized as liable to such servitude. There are both urban and rural

servitudes. The latter involve the right to convey and use from another one's land water irrigation, domestic, stock supply, and for mill purposes. Works damaging others may not be constructed. Damages will be given for use of right of way. Stream courses may not be altered to the damage of those below. They may be changed on one's own land, if no harm is worked for others. Springs can be used by others than landowners for only a certain number of hours per week.

Measurements for distribution are made according to position on the line of supply. All works must be of area easily calculated. Measuring gates are required. Flows must be continuous for a certain time, or when intermittent must be regulated. In fine, the rules are minute, involving all details of distribution. Cost of works are levied pro rata upon all lands served. These works must be constituted to known laws. Owners of springs or fountains or of flowing wells can control them fully. Surface waters become the property of the landowners in twenty years after possession, if he construct works subject to the "servitudes" of others. The flow and distribution from upper to lower levels is regulated by the water laws. When the supply is insufficient the community controls, and resort must be had to equitable terms, some using their share by day and others by night. Indeed, the whole principle of water use places the same under community and legal control.

In Lower California:

Water supply to the cultivated lands is, from mountain streams and also several springs of permanent duration, by law still under the old régime. This country's system of water distribution among planters is regulated through the municipal town council, and is allowed free of taxation, thus being governed by the old rules and regulations of the laws of Spain; the Mexican Government has not yet enacted laws regulating the using of water.

In one of the most important valleys of the Pacific coast, situated in the upper part of the peninsula, 120 miles long by 40 wide, which is entirely without surface water, a valuable discovery has been made of a subterranean stream 70 feet below the surface, which, it is believed, flows through the whole course of the valley.

THE ARGENTINE REPUBLIC.

The Argentine Republic has large areas within its extensive borders irreclaimable without the application of water for irrigation purposes. A system of flooding so that the surplus could readily be withdrawn was in practice before the Spanish and Portuguese occupation; not in Peru, Chili, and Bolivia alone, but on the eastern slope of the Andes, now forming part of Argentina. In his "Conquest of Peru" (Vol. I., pp. 131-133), the historian, Prescott, writing of the soil and its reclaimability by water, states that this—

was conveyed by means of canals and subterranean aqueducts executed on a noble scale. They consisted of large slabs of freestone nicely fitted together without cement, and discharged a volume of water sufficient, by means of latent ducts or sluices, to moisten the lands in the lower level, through which they passed. Some of these aqueducts were of great length. One that traversed the district of Condesuyos measured between 400 and 500 miles. They were brought from some lake or natural reservoir in the heart of the mountains, and were fed at intervals by other basins which lay in their route along the slopes of the Sierra. In their descent a passage was sometimes opened through rocks, and this without the aid of iron tools; impracticable mountains were to be turned, rivers and marshes to be crossed; in short, the same obstacles were to be encountered as in the construction of their mighty roads.

These works were largely permitted to go to decay by the conquerors. Indeed so little care has been taken of them that many of their subterranean channels through which water still flows remain unexplored. In other places they still continue to partially fertilize areas where the conduits are broken through. The system of water laws was elaborate, public and communal in character, but under strict general supervision. Overseers under the royal authority were in charge of management, distribution, and repair. Remains of these works still exist in the Argentine provinces of Mendoza, San Juan, and along the upper eastern slope of the Andes. Since the conquest and up to a recent date agriculture has been greatly neglected. The aboriginal population were almost the only cultivators, until late in the present century.

The interior provinces of Mendoza, San Juan, Catamarca, Tucuman, and Cordoba are those in which irrigation is a prime requirement and wherein it is practiced to an extent that gives evidence of continued growth. The average temperatures of these provinces are given in an interesting report by the United States consul at Buenos Ayres. His figures are summarized as follows:

Provinces.	Longitude.	Latitude S.	Elevation above sea level, meters.	Average rainfall in inches.	
				Apr. to Sept.	Oct. to Mar.
Mendoza.....	68 49	32 55	2,623	.83	3.47
San Juan.....	68 35	31 32	1,131	2.00	2.24
Catamarca.....	60 55	28 28	1,788		
Tucuman.....	65 12	26 50	1,506	2.05	35.00
Cordoba.....				2.27	10.04

Mendoza is on an average, San Juan on less than three years, and the other two on two years each.

Provinces.	Mean of temperature in degrees (Centigrade).	
	Apr. to Sept.	Oct. to Mar.
Mendoza (city of).....	10.61	21.29
San Juan.....	15.09	24.33
Catamarca.....	15.44	26.17
Tucuman.....	14.53	21.19
Cordoba.....	13.54	17.55

The territory of the Argentine Republic extends from 56° to 20° 00' south latitude, so that the variety of climate embraced is as varied as the territorial range is extensive. The rainfall, latitude, and elevation, is given below, as indicating the principal irrigable areas.

These tables illustrate the extreme dryness of the atmosphere, and therefore the need of irrigation. The sources of supply is almost exclusively mountain rivers, streams, and springs, and the trouble with them is their unequal volume. When the snow melts they are full to overflowing, but the waters soon disappear, those in the central system being rapidly imbibed by the sands and possessing no outflow. North and south the streams form part of the Rio de la Plata system, and those south of the province of Buenos Ayres. The distribution is usually of the most primitive character. Dams are built in the streams, and the water is thus diverted at various levels by means of lateral drains, trenches, or ditches with sluices or head gates for admittance to the fields, where checks are used on level ground to facilitate flood-

ing. When the head gates are opened there is no difficulty, as a rule, in evenly filling all laterals, especially in the upper and foothills region. The provinces using irrigation are reported by Consul Baker as follows:

Provinces.	Area in cultivation.	Total area.
	<i>Hectares.</i>	<i>Hectares.</i>
Cordoba	234, 295	17, 478, 700
San Luis	19, 989	7, 591, 700
Mendoza	88, 848	18, 061, 800
San Juan	79, 639	9, 750, 500
Catamarca	44, 618	9, 064, 400
Rioja	22, 217	8, 903, 000
Santiago del Estero	120, 409	10, 225, 500
Tucuman	35, 943	2, 419, 000
Salta	38, 525	12, 850, 000
Jujuy	18, 994	4, 553, 000
Total	703, 077	90, 879, 200

A hectare being $2\frac{1}{2}$ acres (within a small fraction), the total area in cultivation by irrigation will be, in the ten provinces, not less than 1,759,600 acres. The area of cultivation does not exceed 7 per cent of the whole. The chief products are corn, small grains, sugar cane, vegetables, grass, and some fruit. Boring for artesian water has been conducted by the provincial government of Rioja with but little success (1889), however. Catamarca, Rioja, and San Luis are the most arid sections. The best system of works is found in the provinces of Santiago, Rioja, San Juan, Mendoza, and Cordoba, especially the two last named. The figures given by Consul Baker as to the works begun about 1882-'83, by Dr. Juarez Colman, since President of the Republic, show that a number of large dams or dikes, with masonry work, large canals, utilizing different systems, the waters of four important rivers, at an estimated cost when completed of \$15,230,000. Their irrigable capacity is put at 3,020,000 acres, or a cost per acre of \$27.87.

The control of water, where ditches have been taken out wholly by land-owners, remains in their hands. Where construction has been made by the provincial governments a public tax for use is levied. The private control of water is in the nature of an easement, and can not be separated or sold apart from the land on which it is utilized. The original Inca system of public ownership and direction was broken up by the conquest. But as the great estates then created are in process of breaking up, the land sales are always accompanied by a transfer of water also. The public water tax for irrigation purposes in the two provinces of Mendoza and Cordoba is about \$6 per acre (a square is charged \$30 and embraces about 5 acres) for one in seven, the tax to be paid quarterly. Water for domestic use is taxed 25 cents per month for each house or family. In Catamarca the price is 6 cents per hour. In Tucuman \$3 per mark for twenty-four hours' flow. In Santiago all farms and gardens pay \$1.50 per hour for all the water they use, six times or six days in a month. There is a statement in the law of a limit to amount of water to be used.

NICARAGUA, VENEZUELA, AND CUBA.

Irrigation is practiced to some extent in Venezuela very much after the usual fashion of the ranchers and laborers of mixed Indian and Spanish descent. The small streams are the chief source of supply. Coffee requires a good deal of water, as does sugar also, and the great

heat of summer rapidly evaporates the flowing water; as a result the crops suffer from drought. There are no important works and no water code or regulations. United States Consul W. S. Bird reports:

The system of water distribution is governed, according to the best obtainable information, by custom only, although there are some statutes in reference to it that, by common consent, have fallen into disuse. The unwritten law is that each person shall have the right to water on a stated day for a certain length of time, when he must close his flood gate and again await his turn. Under such an arrangement, therefore, it is evident that the amount of water used per acre and per season, and the tenure of ownership, etc., can not be intelligently stated.

Nicaragua uses irrigation only in a very perfunctory way. Mr. H. C. Wills, United States consul manager reports that near Nandaime, a small Indian town in the department of Rivas, three cacao (chocolate) estates are partially flooded in a primitive way by their owners from small rivers or streams being dammed to cause the water to flow over the plantations, which are below the streams.

Some action has been taken in relation to artesian wells, several of which were being bored in 1891, with fair prospects of obtaining good flows. The water is to be used in coffee plantations.

A system of small irrigations exists in Cuba, according to our consul at Santiago de Cuba. There is an abundant water supply, but the summer heat and topographic conditions seriously affect the distribution. The rivers and small streams are numerous enough to fill the soil by percolation and so make natural subirrigation an availing factor. "Los Cantos," a sugar estate on the Bay of Guantnamo, owned by an English firm been have compelled to construct open ditches and irrigate 333½ (10 caballerias) acres.

The water supply from the Guantnamo River is dammed above the area irrigated and the water distributed by a system of small ditches. Permission was obtained from the Spanish Government, and the owners pay neither rental nor taxes. The amount of water used per acre depends on the rainfall of the rainy season, and can not be estimated, as the work has just commenced.

IRRIGATION IN EUROPEAN COUNTRIES.

AUSTRIA-HUNGARY.

Consul-General Goldschmidt, at Vienna, reports that in Austria-Hungary, meadow irrigation on a large scale, although generally in an imperfect state of construction, may be found in the southern part of lower Austria; in the Mattig Valley, in upper Austria; near Klagenfurth, in Carinthia; in certain of the upper and central valleys in Tyrol; on the farms of Prince Schwarzenberg, at Wittingau; at the imperial and stud farm at Kladrub; in the Bistritz Valley, and in the Elbe Valley in Bohemia.

The water required is, according to local circumstances, taken either from rivers, creeks, springs, ponds, or other reservoirs. As a rule it is conducted from rivers or creeks with its natural head into channels or ditches. The water course is generally stemmed, more or less high, at the place where the conduit is to be started, by a suitable dam, which will cause the water to flow into the irrigation channel. The latter is at its source or beginning generally provided with a gate, which serves to protect it from floods and to permit of its being laid dry when required.

For small meadows there are in many places found wheels for raising the water from the natural watercourse (creek or river) to the higher border land. These wheels are equipped with buckets, which are hung in and are moved by the currents of the streams in which they are suspended. They are found in large numbers on the Eisack River, in Tyrol, above Bozen. For irrigating extensive meadows at Kladrub, in Bohemia, for instance, a 30-centimeter centrifugal pump is put to work when the Opatovic Canal contains too little or no water. This pump is then operated by a 12-horse-power portable engine, and raises the water from the Elbe River to a height of 5.5 meters.

Wells, tanks, or cisterns are generally employed for the irrigation of kitchen gardens only. Arrangements of this kind may be found in the environs of large cities, especially around Vienna. In this kind of irrigation the water is, as a rule, pumped from the well, tank, or cistern by means of horse power.

In localities where but small supplies are found in creeks or springs, basins or ponds are formed by the erection of suitable dams.

Such small basins or ponds have been constructed, for instance, at the trifling cost of 100 florins at Guttaring, in Carinthia, for the irrigation of a large meadow of 3 hectares, and on the Saager farm, in Carinthia, for a meadow of 1.7 hectares, when the total cost of construction amounted to only 85 florins.

Consul-general Goldschmidt says, that:

In Austria there exist no special institutions for the supply and distribution of water from the main conduits (canals, etc.) for irrigation purposes, as, for instance, the so-called "water module" in upper Italy. Such arrangements are not known in Austria, for the reason that here no independent enterprise exists for vending quantities of water from canals. The distribution of the water into the different side ditches is effected by simple, mostly wooden, gates, which are raised or lowered according to requirement.

There is no general code in relation to the use of water, and when impounded it is regarded as private property. Provincial laws exist for the control of water corporations, which provide, among other uses, that of irrigation and drainage. The corporations have a municipal or district character, and the propriety and need of inaugurating either irrigation or drainage enterprises is to be decided by votes that represent the preponderance of acres in the area to be affected. Another law

passed in Austria June 30, 1884, provides subventions from the states and provinces to the extent of 60 per cent of the total cost of irrigation and drainage constructions. In the Goriz district irrigation for rice is practiced. Irrigation for grain fields is now planned in connection with the Marchfeld plains, near Vienna. In the mountainous portions of the Tyrol meadow irrigation is both ancient and extensive. Many old irrigation works have been reconstructed and improved, and new ones have been constructed in great numbers.

Several of the Bohemian canals constructed for power and navigation are also used for both drainage and irrigation. The same thing is true in Austria.

BELGIUM.

Irrigation is practiced in Belgium, chiefly for the cultivation of meadow lands. There are numerous small works and canals for that purpose. There are 16 navigable canal systems with a total length of 587,773 meters (367.3 miles), the water of which is often used in agricultural processes, as, for example, in the flooding and draining of the flax pits in aid of the process of "*rouissage*," or decomposition by "retting" or "steeping" in water. These canals are all the property and under the control of either state, province, or commune.

A net work of canals known as "*de la campine*" are the chief artificial channels used for the irrigation of meadow and moorland. Considerable use is also made of the rivers Scheldt and Meuse, and their affluents. The canals named have a length of about 350 miles, and were constructed for both navigation and irrigation purposes, at a cost of \$5,000,000. There is considerable and successful enterprise in the way of reclaiming moorland by means of irrigation. The profit already obtained is about \$22 per hectare (nearly 3 acres). Consul J. A. Stewart, of Antwerp, says:

No tax of any kind is collected for the use of the water of the canals for irrigating purposes, and no engagement of any kind exists between the parties interested, i. e., the state and the proprietors of the land under irrigation. Such proprietors have a uniform right to the water available from the canals, the requirements of navigation having been previously satisfied. Permission to establish trenches from the canals for irrigation are generally granted under certain conditions. They have to be constructed according to plans sent in with the application, and approved by the Government. The applicant will be held to keep the land irrigated under cultivation, and not use it for any other purpose.

DENMARK.

Irrigation for reclaiming heath land is carried on in Jutland, Denmark, by a corporation organized for that purpose. About 90 square miles or 55,000 acres, out of 140 square miles or 71,600 acres, have been brought under use, 6,400 acres as plantations and the balance as meadows and fields. The work done is divided into: "(1) Construction of irrigation canals; (2) plantations in general; (3) limited plantations on the different properties and inclosures with quickset hedges; (4) draining of bog lands; (5) cultivation of marsh lands."

There are 145 canals in operation (1890), carrying 22,000 second-feet of water and having a varying length of from 5 to 15 miles. The 21,000 acres of land under cultivation have increased in value \$1,600,000, or nearly \$80 per acre. The total cost is estimated at from \$80 to \$270 per second-foot, or a total of not less than \$300,000, and administration is arranged by each canal. One crop is made per year, a local board is chosen, and they divide the water each season; that is, from April to December. Conveyance to meadows is made in wooden troughs.

In all there are 51,400 acres of forest plantations. The corporation controls and owns 6,300 acres for experimental planting. Its work forms a very interesting reclamation exhibit.

FRANCE.

According to the report of Consul-General Rathbone (1891), the total area irrigated in France is 7,000,000 acres. All irrigating canals are river-fed. Reservoirs are few in number. The works consist, first:

Of a principal canal, or chief branch, through which the volume of water to be distributed flows from the river; second, of a smaller canal, fed by the principal one; third, of a network of streams, drains, and ditches, which provide each landowner with the quantity of water to which he is entitled.

The use of water for irrigating is regulated by the French code. The articles bearing particularly on this point are as follows:

643. The owner of the spring can not change its course when he provides the inhabitants of a commune, village, or hamlet with the water necessary for them, but when the inhabitants have not acquired or prescribed the use of the same the owner may demand a compensation, the exact amount of which is to be fixed by an expert.

644. The owner of a property skirted by a running water which is not national property, according to article 538, has a right to the use of the water for irrigating his lands while it flows past them. The owner of ancestral lands traversed by this water may use it within the full limits of his lands on condition he restores it to its proper bed before it leaves his estate.

645. If a dispute arises between the landowners to whom this water may be useful, the tribunal called upon to give its decision in the matter shall conciliate the interests of agriculture with the respect due to the rights of property, and in every case with the particular and local customs and regulations which pertain to the passage and use of water.*

Recent enactments provide for some additional rules, the text of which is not at hand. Springs are owned by persons, by the state, or by the communities. Running waters are regulated, as to use, by law. Navigable waters belong to the state. Irrigation works are executed either by syndical bodies or by contractors working for public bodies. A hectare is very nearly three English acres, and the cost of water on several of the leading canals is given per year at from 35 to 80 francs per hectare, or from \$2.33 to \$5.33 per acre. Consul-General Rathbone states that:

The cutting of a certain number of canals for irrigation in the southern districts dates back several centuries. The more important works, however, are of comparatively recent origin. During the last ten years, especially, a great impulse has been given to the construction of works devoted to irrigation. Subjoined is a list of the most notable enterprises of this kind. It is taken from the "Journal d'agriculture pratique."

Departments.	Description of works.	Cost.
		<i>Francs.</i>
Drôme.....	Canal de la Bourne.....	13,000,000
Alpes-Maritimes.....	Canal de la Vésudie.....	7,000,000
Aude and Hérault.....	Canal to be used for submerging both departments.	2,400,000
Drôme and Vaucluse.....	Canal de Pierrelatte.....	8,000,000
Basses-Alpes.....	Canal de Manosque.....	4,500,000
Hautes-Alpes.....	Canal de Ventavon.....	3,000,000
Aude.....	Canal de Canet.....	1,000,000
Bouches-du-Rhône.....	Drying up the Fox marshes, and purifying the waters of the Crau.	18,000,000
Hérault.....	Canal de Gignac.....	4,200,000
Loire.....	Canal de Forez.....	7,000,000
Alpes-Maritimes.....	Canal de Foulon.....	1,200,000
Aude.....	Canal de Cuxao.....	2,000,000
Do.....	Canal de Luc.....	} 1,100,000
Do.....	Canal de Fabresan.....	
Total.....		\$1,400,000

*Consular Report on Canals and Irrigation, 1891, p. 99.

The public treasury generally contributes one-third of the cost of the works; the land owners interested in them defray the remaining two-thirds. In the case of the most important works, the State, besides contributing its third, has guaranteed for the space of fifty years to the parties who covered the loan raised for the purpose of carrying out the works the interest due on the sums lent to the contractor.

The department of des Bouches-du-Rhône borders on the Mediterranean to the east and comprises the territory surrounding the mouth of the river. The chief source of supply is the Durance River, a mountain stream of considerable volume. Its floods have often been destructive in character. The area of irrigated land has largely increased during the past thirty years. The water surface (artificial) devoted to irrigation purposes was given some years since at 1,378 acres, while that of the natural lagoons, rivers, lakes, and streams is stated at 134,500 acres. The cultivated area was given twenty years since at 876,000 acres. It is now about one million. The products of this department include olive orchards, vineyards, and other semitropical fruits and products. The cultivation of wheat is also increasing. The small farming of France reaches its best development in the south of France. United States Consul Trail, of Marseilles, says:

Properties of this sort are frequently not more than 20 acres, sometimes much less, that being all the land one average family can cultivate without the employment of hired labor. The products of such a farm are raised on small patches. One frequently sees but 1 acre given to wheat, another to the vine or olive, several for gardening, and the remainder in pasture on a 10 or 15-acre farm. This diversity of production prevents the farm work from being overexacting at any one period, enabling the family to work on the different crops at different times, and keeping it busy all the year round. Besides, it is found, even on these small farms, that marked differences in the soil occur, so that experience has taught that it is more profitable to divide up 10 acres in several cultures than to confine them to but one. These small farms require little or no machinery in the American sense of the word.

Irrigation in this department is as ancient as the Roman occupation of Gaul. At that early day canals were dug to conduct the water of the Durance to Arles and Salon in the southward. All subsequent authority has encouraged these irrigation efforts, however rude they may have been. Syndicates have been formed to construct roads, against the sea and the river and floods, to drain lagoons, to irrigate the land. For drainage purposes there were in 1890 fifty-three of these syndicates, and for irrigation eighty-one. There are two classes, one under Government control, and the other elected by those interested. Each syndicate represents one work, which makes eighty-one, the number of canals, the largest of which are the Craponne, the Alpines, and the Marseilles, for all of which the Durance is the source of supply. The first-named system was constructed in the sixteenth century. It irrigates about 30,000 acres. The canal supplies the city as well as the land under its course by a system of ditches, conduits, and pipes exceeding 100 miles in length. The annual receipts are about \$300,000, and the cost of water for irrigation is from 27 to 190 francs annually, or from \$5.40 to \$38 per year. Water is sold by the measure, not by the acre. Consul Trail says:

The French law permits a farmer to use all the water necessary to irrigate his fields from a river flowing through or by his land free of cost. When the land is lower than the river surface the question of embankment may be the most important for that particular property; when above the level, the cost of pumping the water up to a desired point for immediate distribution or for storage in a reservoir takes a most important place in the items of yearly expenditure for that estate, so that the value of rural property is governed by the ease and cheapness with which water can be obtained, or the contrary. Where nature alone has to be relied on for the rainfall the value of land, as given before, is very low, as the only products under that condition are a coarse and scanty grass and a few trees of little or no value.

In answer to the question sent in 1880 by the Senate Committee on Irrigation and Reclamation of Arid Lands, through the State Department, the various United States commercial agents in the Marseilles consular district state that there is under irrigation in nine communes a total of 93,762 acres. These questions, prepared by the writer as the committee's expert, were as follows:

- (1) Areas of land under irrigation; compare with the nonirrigable and cultivable areas when possible. Also, quantity and quality of crops grown.
- (2) Sources of water supply, whether from rivers, streams, springs, lakes, wells, reservoirs, catchment basins, or tanks, etc.
- (3) Character of works used for storage and distribution of water.
- (4) The system of water distribution, whether governed by laws, rules, and regulations, or custom. Give duty of water per hectare, *i. e.*, the amount used per hectare and per season; the cost or rental to user; tenure of ownership of water, and whether the same be public or private, national or community.
- (5) Character of climate in irrigated region and nature of soil; annual rainfall or other precipitation.
- (6) Antiquity or otherwise of irrigation systems within the section treated of, and whether the same are maintained at public or private expense.

There are private ditches, and some controlled by riparian rights, but the larger number are the property of the communes themselves.

The United States consul at Ronen, Mr. Williams, writes of the river and canal revenue and funds, as follows, so far as the subject in the north of France refers to irrigation and forestry:

The rivers serve other purposes, such as reservoirs for man and beast and domestic purposes, and irrigation of the streets of villages and cities and irrigation of land. For the last-named purpose this district has no use. A considerable source of revenue arises from the sale of forests planted on lands redeemed by dikes, and the banks of canals upon which trees—principally willows and poplars—are grown, which sell on an average at 20 francs apiece at the growth of thirty years.

The revenue from this source alone was 345,053 francs in 1887. The wood sales of the navigable waters of the department of the North and Pas de Calais were, from 1883 to 1887, 69,500 francs, and will be much more when the growing groves will be matured. The net profit of the sale of 18,000 poplars on the Seine was 414,000 francs in forty years, or 10,350 francs per annum. The trees add not only to the beauty but to the comfort of these waterways.

The falls are utilized as a motive power, and they become vast reservoirs where fish are extensively propagated. They sometimes break through their banks and do much damage to lands, and become the depositories of much unhealthy matter and require great outlay for repairs.

The importance of the waterways of France is conceded on all sides, and their extension and amelioration have received the careful consideration of every administration, and of none more than the present.—(Canal and Irrigation, Consular Report, 1891, p. 119).

The Forez Canal, in the Department of Loire, and supplied by the river of that name, irrigated 65,000 acres. It was begun in 1863, and the National Government has granted for its construction \$122,200, and loaned the balance needed to the department at 4 per cent. In 1886, date of latest report, there were 23,000 acres served, with a length in ditches of 115 miles, at a cost of \$219,104, or nearly \$9.50 per acre. At that rate a total cost of the system will not be less than \$598,000. The water is sold by volume under gauge. The distribution is in general periodic and collective, through pipes carrying the water to a point most convenient for a group of farms. From the pipes head or flood gauge the water flows into farm laterals. This service is always once a week, on the same days or hours, the amount received being regulated by the amount purchased. The delivery commences on land furthest from main canal. Each proprietor turns off the water from his lateral when he has received what has been paid for, and the next in order is served. The system works well. The assessment tables are made out by November 1, and notice is served on each irrigator of the

days and hours when water was applied to each parcel or piece of his land. The smallest proprietor is served at least two hours, and the amount ranges from 7 to 15 liters per second. This irrigation is almost wholly employed on meadows. The methods are small ditches on slight grades or by wooden troughs where the land is flat. The results obtained are stated to be profitable and satisfactory. Land has increased in value from about \$44 up to \$300 per acre.

The Department of Lozère is the most elevated in France. Irrigation is practiced there quite extensively, but in a primitive fashion. The fields are flooded by cutting the stream banks. All springs are collected through pipes and delivered to the land. The people of this department make their own water regulations. Riparian rights, regulated by needs, are recognized. The water must be restored to its natural course after use and be received by those below. Passage over other lands is permitted on indemnity for all works necessary to convey water. Courts have summary jurisdiction, and the prefects may make police regulations, if required.

ITALY.

Irrigation in Italy was probably as ancient as the rule of the Etruscan people. It certainly was an early and important part of Roman economics. It has had a distinct purpose in the agronomic life of the peninsula ever since. But its present importance dates from the works inaugurated by that almost universal genius, Leonardi di Vinci. At the present date the principal seat of cultivation by irrigation is in Piedmont and Lombardy. In 1878 there were the following areas under cultivation by irrigation:

	Acres.
Lombardy	2, 034, 070
Piedmont	1, 329, 000
Venetia	122, 000
Emilia	288, 000
Other provinces	642, 090
	4, 415, 000

There are nine principal canals in Lombardy which are navigable as well as used for an irrigation supply; the mileage of the system is extensive. The Piedmont main canals are 253 in number, with a length of 1,207½ miles. Venetia has 203 navigable and 40 minor canals. The latter are chiefly used in irrigation. It is estimated that about 500,000 additional acres can be brought by these means under intensive cultivation. In the last twelve years there is no doubt that the increased acreage under irrigation will make the total at least 4,600,000 acres. In the Progress Report for 1890 of this office the local laws and regulations are given.

United States Consul Edward Camphausen, at Naples, writes:

There are some lands under private irrigation. The water supply belonging to the respective landowners is taken from wells at a depth varying from 25 to 100 feet, water being found in abundance at that depth in most parts of the country. Near the coasts of the Adriatic and Mediterranean wells are formed by the infiltration of saltwater. Some of these belong to communities, but no definite law or regulations appear to exist for the use or distribution of the water, and there is no irrigated land in the true sense of the word in this district.

The Italian Government has expended large sums of money since 1865 on irrigation works, and in 1883 it was empowered to loan funds (principal payable in thirty years) at 5 per cent to "irrigation associations" (consorzi) and to provinces and communes for the purpose of

carrying on works of irrigation; provided the supply of water to be obtained shall be not less than 25 gallons per second, and provided the province or commune advances an amount at least equal to one-tenth of the sum loaned by the State.

In Sicily especially, and throughout southern Italy, all fruit culture is carried on by irrigation, which is in all instances required throughout the summer months, the proportion of nonirrigated to irrigated groves in extent being as 1 to 15. One hundred 10-year old lemon trees that are watered produce on an average 15,000 lemons; whereas 100 trees that receive no water (other conditions being equal) produce but 10,000, or one-third less. The groves are watered from twelve to twenty-five times during the summer; that is either once every two weeks or once a week. At the last spring working of the trees the land is trenched, in order to obtain an equal distribution of the water. Parallel trenches are opened (generally about 6 inches deep and 8 inches wide at the bottom) between the fows of trees, the intermediate space being divided into symmetrical squares or divisions.

Prior to 1866 the water for irrigation was owned by private individuals, the municipality, and convents, or religious corporations. In that year, however, the Government confiscated all the property of the latter to which there was a clear title or in which no outsider, public or private individual, had an interest, so that now it controls all the water formerly owned by the religious bodies in question, which by far exceeded that owned by the municipality and private persons combined. This water the Government either sells or rents.

According to the reports of our consul at Messina, the—

Distributing of water for irrigation purposes when the water is private property (for by law the owner is allowed to make what use of it he pleases provided he does no damage to his neighbors) is not governed by law, but by special customs that vary with the locality, and which it would be impossible to enumerate. The cost of water for irrigation purposes is so complicated a matter that it can not be fixed precisely, but this much can be said: In this province a penna (a goose quill) of water, i. e., 36 gallons of water, per hour costs from \$200 to \$260 per annum.

Here, as a rule, water, is private property. Some communes own water, either by purchase from private parties or because its source is on community land.

The title to water is acquired by bargain and sale, exchange, gift, and can also be acquired by prescription. Not less than thirty years of undisturbed enjoyment are necessary to create title by prescription.

Irrigation is commenced on April 15 and terminates September 15, annually. For obvious reasons it is not resorted to during the winter, excepting for promoting the development of grass lands.

SPAIN.

The total area of irrigation in Spain is variously estimated at from 700,000 to 6,000,000 acres, the latter being the estimate given by United States Consul Perez, at Santander, of the area benefited by irrigation. The first-named estimate embraces the cereal, vegetable, and fruit area; the latter that of the forage plants and grass lands. The total cultivated for crops and pastures in the kingdom is given by the same authority at 120,000,000 acres. One of the most notable plans for irrigation is that applied to the cultivation of meadows in the northern coast provinces and known as the "spike channels." Mr. Perez says:

The system for irrigation of meadow lands most commonly applied in these provinces is that denominated "irrigation by inclined channels," or also "spike channels" ("riego por requeras inclinadas" or "requeras en espiga"). The distribution channels are devised nearly in the sense of the greatest slopiness of the grounds; the irrigation channels connect with them and spread out to right and left. A rapid

sectional change takes place in the distribution channels at the point where they separate into branches with the irrigating channels. The last-mentioned channels, by having a gradually narrowing section from their parting point down to the opposite end, pour out the water by getting inundated. Another contrivance is also combined with this briefly described distributive system, which consists of collecting channels, called "azarbes," dug on the natural lines of junction on the meadow ground, terminating in an outlet channel. Sometimes, when the extent of the meadow is not considerable, or when the quantity of water available is but small, the collecting channels are changed into new feeding channels for the supply of other lots situated farther down.

Any reasonable attempt to illustrate the irrigation works and methods of distribution would require a volume in place of the few pages at the writer's command. It will suffice to say that irrigation in Spain goes as far back as Iberian life, existed under the Roman conquerors, was systematized and localized by the Moors when they controlled southern Spain, and that it has within the current century taken a new lease of life and enterprise. Engineers study the works of Spain for their construction merits; and as among the applications of hydraulic principles, legislators find in the codes and laws adopted by the national government as well as in the rules, regulations, and customs by which provincial local and municipal control is maintained over the natural wealth-water, a constant series of models for application elsewhere and under almost all varieties of circumstances. Agronomic economists are guided at every step by Spanish experience in learning and estimating economy in the use of water, the value of land and products under irrigation, and the means and methods by which such results are achieved. The former Spanish control of large areas of our own territory has left marked influences upon the conditions under which irrigations must be operated. The study, therefore, of Spanish irrigation results, laws, regulations, customs, and of the constructions in use, will prove of value to all who desire to understand the legislative and economic, as well as engineering needs of an arid or sub-arid country, whose agriculture must be largely carried on by means of irrigation.

IRRIGATION IN BRITISH DEPENDENCIES AND COLONIES.

IN BRITISH COLUMBIA.

The southern and central portions of this section of British America has most of the characteristics of eastern Washington, and requires, as it does, irrigation for security of crops. The climate is dry, the rainfall quite small. The interior is a great basin, broken by small ranges and hills not much elevated, and is drained by the Frazer and Thompson rivers, and lakes. There is a marked absence of forest trees and the river basins and valleys are of great size. Irrigation is practiced to a moderate extent at several points, notably at Ashcroft, where irrigation is used in general agriculture and fruit growing. There are a number of ditch enterprises; one, known as the Boston, being 14 miles in length, and costing for construction \$60,000, \$4,285.71 per mile; somewhat less than \$5 per acre. This ditch failed from want of good engineering and cost too much. At Hat Creek, near Ashcroft, there is an enterprise drawing water from a small lake and costing about \$5,000. From the eastern slope of the Cascade range to the western one of the Selkirk Mountain, or as far east as the one hundredth meridian of west longitude, the storage and conservation of water for irrigation will become a necessity whenever farming begins on an extensive scale.

Mr. C. F. Cornwall, a prominent citizen of British Columbia, writes to United States Consul Stevens that there are a number of irrigation enterprises and that without it—

The cultivation of the soil in such portions would be fruitless; with it the most satisfactory results are attainable and attained. * * * Though irrigation of land undoubtedly adds a certain percentage to the expense of cultivation, yet I think it can be indisputably proved that the advantages resulting from its use amply repay the increased cost. The average yield of crops under well-applied irrigation is very large; far larger than in unirrigated districts, however fruitful they may be. The use of the water, doubtless to a certain extent, enriches the land, and so rapid is growth under its beneficent stimulating effects, that in these comparatively northern latitudes produce is brought to a perfection of species which you would only expect to find flourishing in more southerly climes; for instance, besides all the usual grains and roots common to temperate climes, in these districts, under irrigation, flourish fruits of all descriptions—grapes, melons, cucumbers, tomatoes, maize, apples, pears, plums, etc., all too numerous to mention—and attain a maturity and perfection which is astonishing. Such would not be the case were such latitudes subject to the cold which is associated with a degree of rainfall which would render irrigation unnecessary. I think that most farmers who have experienced practically the advantages of irrigation would be unwilling to pursue their avocation in districts where its use was unnecessary or impossible.

Legislation in this province, adopted in 1873, making provision for ditching and diking, goes into administrative details with great care so as to retain control in the hands of the authorities. The act provides for the appointment of district commissioners, specifies their powers, and directs them how to carry on the work,—for cases in which the land is partially owned by the crown; for overseers; how to give notice to proprietors; how and for what, assessments, fines, and rates are to be made;

provides that lands may be leased or sold for payment of rates; that the land is liable only where the owner has not agreed to the works or for actions by owners against commissioners; that owners and occupiers shall furnish labor; fine may be levied for neglect of assessment of damages to sods or soil; that record is to be kept by clerk; the fees for inspection and extracts; as to cases of salt marshes and necessary breakwaters; assessment may be made only upon land benefited. Clerks are to be competent witnesses; commissioner must not be a clerk; how plans may be obtained; as to outer dikes and inner dikes; how kept, outer dike ceasing to protect inner; proprietors of inner dikes have recourse to compel repairs of outer dikes; injured dikes, how repaired; mode of making application for drainage—duty of commissioner; mode of valuing and assessing damage to lands—cases of two proprietors, but neither owning two-thirds, how provided for; occupant may appeal to Supreme Court; fine for official neglect; verbal notices valid unless otherwise specified; commissioners not liable for acts of predecessor; lieutenant-governor in council may in certain cases guarantee interest on two-thirds money for diking; assessments for the interest so guaranteed, lien on the land therefor.

BRITISH AND NATIVE (DEPENDENT) STATES OF INDIA.

The peninsular region of India embraces irrigation, engineering, and economic problems of the first magnitude. Topographically speaking it is an area remarkably self-contained. As related economically and socially it is self-developed. In climatology, though it largely lies under the equator or is close thereto, it has many distinct types, and ranges from the lowest to the highest degrees of humidity and precipitation, of heat and cold. In population the region is one of the largest; in racial and ethical associations it possesses many and varied conditions. To the agriculturist and economist interested in irrigation questions, it presents peculiar attractions. In formation India is an equilateral triangle, whose apex is the "roof of the world"—the vast central Sierra of Asia. The distinctly arid portion embraces the Himalayan Range and projects southward, like a huge diamond in shape, into the elevated central plateau of the peninsula. The shore portions, made from river deposits and practically their several deltas, are somewhat in the shape, on either side, of elongated triangles whose lower points meet in the Indian Ocean. The western triangle is the wheat region; the east the rice growing. At the south are the cane fields and other tropical products. In the arid section or plateau region the cereals, millet, maize, barley, sesame, etc., are grown. There are many important streams and several of the world's great rivers. They are both snow and rain fed in character, the latter being the largest and most important. The Indus, Ganges, and Brahmapootra are all larger than the Nile, the latter being four times as great in volume. The population of India follows rainfall, and evaporation producing aridity, renders the crowded life precarious. The soil of India is almost everywhere saturated with moisture. Mr. Deakin says: "By far the largest section of all is watered by wells," and their contents are lifted by means of "hand or bullock draft." Except at the head of the sub-mountain plains, where the supply lies too deep for present use in an economical manner, "there is water under the soil almost everywhere." Even in the sub-Himalayan provinces, "the plains are honeycombed with thousands of wells stretching southward."

The Crown is the general landowner. Legally speaking, it is the only

landlord. All waste and unoccupied lands are distinctly controlled by the imperial administration. Their use adds to the common wealth and gives security to the empire. Irrigation offers the way for use. Since the Indian authorities have perceived the relations of land and water, as vested in a representative source and an administrative authority, learning the lesson left by the seven famines of the last half century, they have been sedulously endeavoring to re-create older Indian forces and habits with modern capacity and capital, to make safe the tiller of the soil; and to insure them against famine and its horrors. There are nearly 131,232,180 acres under cultivation, less than one-fourth of which are under irrigation works. There are 80,000,000 more, according to Prof. Wallace, that can be reclaimed. There have been large additions in this generation to the cultivatable area in Madras, the northwest provinces, Bengal, Sind, and the Punjab, while gaunt famine is slowly but surely passing away. The farm villages have increased by many thousands and the land or rent revenues have grown in proportion. The policy of loaning for public works, especially those of irrigation, has had much to do with this progress. It has become so settled a course of action that 75 per cent in value of all land that can be irrigated, and so improved, may be borrowed of the imperial administration. It is worth while to inquire into these facts, which among others have made of the Indian ryots, in wheat exports, the most formidable of competitors to American farmers.

There are two seasons or harvests per year over the larger portion of India, known as the "kharif," or summer, and the "rabi," or winter season. The "kharif" is the season of greatest rainfall, and in the low lands, the northwest provinces, Bombay, the Punjab, and Central India, the precipitation is reckoned per season at from 20 to 40 inches. In "rabi" the rainfall ranges from 2 to 10 inches per season. The southern central portion and Sind may be compared with Arizona, southern Utah, and the San Joaquin Valley, California. This twin irrigation often doubles the crop capacity. The government control of irrigation works and administration is practically absolute outside the native states, and within them the idea of common or public property, strictly prevails. It disposes for use of all water, controls and manages the same, and it directs the distribution thereof. Water rates are assessed on irrigated areas, and these vary according to crops raised; so also does the amount of water required, some crops being more thirsty than others. Community ditches and works are constructed and conducted under official supervision by the villagers themselves. Canal officers measure and oversee the supply. There are presidency departments of land, revenue, and water supply; also of public works, and a general department at Calcutta for the whole empire. Engineers in chief, superintending executive, and assistants—are appointed. They all have magisterial powers in the line of their duties. There are native deputies, magistrates, constables, and overseers. The chief engineer in each presidency or province is in authority, subject to the Indian council at Calcutta and the secretary of state for India at London. The Indian canal works are divided into "perennial," supplied by and subject to regular seasonal fall; the "inundation," subject to torrential filling and sources; storage and drainage works. There are also the native wells and tanks, all of which are carefully encouraged and looked after by the government. The one division may be termed general and the other local. The inundation canals are found chiefly in the great valley of the Indus, and their main feature is the absence of permanent head works. This is in striking contrast to the suggestion made in the United

States by one class of theorists in irrigation matters, that the use or storage of storm, torrential, or inundation waters must be accompanied by the creation of costly works, to be placed as a rule at high altitudes and under topographical conditions that are likely to insure the rapid washing away and destruction of dams and embankments as well as the silting up of channels. Possibly a solution of the more important problems involved may be seen in the utilization, as under the Maxwell system upon the Raton table lands in northeastern New Mexico, of great natural depressions on the open plateau as storage reservoirs. In this case, the mountain supplies are drawn direct from the cañon streams and conveyed by large artificial channels to the old lake beds or great playas which abound in the table lands. From these the distribution is easy. But, returning to Indian works, we find that for inundation canals the supply stream must generally flow at a relatively high level to the section to be watered. The channel bed should follow a ridge; in other words, be a "high line" canal. Sometimes the water is thus conveyed over lands by channels that are higher than the fields. Other canals of this class must be constructed with rivers subject to long annual overflows. A thorough system of drainage is a necessary part of such works, as otherwise there is seen the "reh," or rising alkali, the undue rise of the sub-surface water level, the creation of marshes, accompanied by epidemics of chills and fevers. The perennial canals are an accompaniment of the mountain-fed streams and supplies, such as the Jumna, Ganges, Sutlej, and others. Many of these streams will rise during one season from 5,000 to 300,000 and even 1,000,000 second-feet. Mr. F. A. Franklin, C. E., of the New South Wales water supply department, in a report on certain aspects of Indian irrigation, gives in one paragraph so clear and simple a description of the same that it will bear quoting. It is as follows:

The main channels in every case are formed on the ridges to be found on each side of the main rivers. These ridges, which exist in varying widths, right and left of the river channels, have been formed by the gradual deposit of alluvial matter when the rivers have been in a state of flood, and they occur at points where the velocity of the stream is checked. The effect is to leave on each bank a stratum of silt, in the sectional form of a long wedge, with the thick end towards the river. The width of this slope on the plains of India varies from 300 yards to a distance of many miles. Beyond these deposits, which occur also on all tributaries of such rivers, the country is low, and although not perceptible to the eye, yet instrumental examination shows in which direction the drainage tends to flow. The irrigation of India is therefore based on a very simple principle.

Madras, with a population of over 31,000,000, and the great alluvial delta made by the mouths of the Godavari, Kistna, Penner, Kaveri, and Tramparani, contains a number of the largest and most useful irrigation works. They are divided into "productive," "protective," "minor," and "navigable." The first are works constructed from government loans and charged with interest; the second are works designed for protection against famine. The others are local works, or those connected with navigation, but incidentally only in aid of irrigation. The investments up to the year 1890 are as follows:

Productive works	\$25,840,000
Protective works	768,000
Minor and navigation	5,880,000
Total investment	32,488,000

The pound is estimated at \$4.80. This is slightly below exchange, but affords the most convenient unit of computation, and is sufficiently accurate.

The acreage watered is given for 1889-'90 at 6,000,000. Of this total 2,300,000 acres are under the major works. In addition to a very large increase of land revenue, the revenue from water supply was \$8,400,000. The deficit in interest on loans was \$1,726,160, deducting which the net return for the fiscal year 1889-'90 was \$673,840. This is in addition to \$480,000 remitted to land owners. State irrigation in Madras is, therefore, a direct and brilliant pecuniary success. Before the Anglo-Indian administration assumed control there were only 750,000 acres irrigated, mostly from wells and village tanks. A direct addition of 5,250,000 acres has been added to the area irrigated, and the revenue has swollen from \$432,000 per year to \$2,400,000. The present value of irrigated crops is stated at \$79,200,000. In fact, the Government investment pays from 30 to 45 per cent per annum. The native people are well off. Of the land seven-eighths is controlled by those who work it. There are 35,000 villages, each with less than 500 inhabitants.

The ryots have become [says Mr. Deakin] by tradition and practice experts in the art of irrigation, though their greediness and selfishness often lead them to apply too great a volume of water. Unless they are watched they will at any time of need turn drainage cuts into irrigation channels by damming them, to the injury of their neighbors and of the system. There is no feeling of obligation on their part to the State or its officers, but, on the contrary, any attempts to improve the alignment of works are met at once by exorbitant demands for compensation. The harvest which irrigation has brought them is thus often used to fight the Government, which has given them the means of irrigation.

The great Madras works were originally planned as huge private enterprises, but their failure as such was so conspicuous, that the presidency authorities were compelled to buy them all in at a cost of \$10,367,260. Free water was granted for five years, from 1882 to 1887. At present, until 1892 only one-half the water rate has to be paid. The nominal cost is 24 cents per acre; the actual cost is 12 cents. Perpetual maintenance is provided for on a total payment of 48 cents per acre. But the primitive native system still largely prevails. The number of wells used for irrigation is not returned, but it is not less than 30,000, and the area they serve is at least 3,000,000 acres. There are 60,000 village tanks or reservoirs, whose embankments of 6 feet in height, says Mr. Deakin, would if stretched out make a girdle $1\frac{1}{2}$ times the circumference of the earth. The Australian statesman says:

We find first and most often the well. There are wells in the north, center, along the eastern strip, and in all river or other basins; river-fed canals in the north and northwest; deltaic canals in Sind, Bengal, and Madras, and reservoirs in the interior plateau, on the west coast sometimes feeding canals, and on the east often dependent solely upon rainfall. The natural conformation of the country has been studied and followed by its inhabitants. Wherever there has been water available it has been eagerly seized upon. Whether by well, by reservoir, or by canal, it has been caught and utilized. Wet cultivation is being carried on in all quarters and in all conditions. In a word, where the rainfall is deficient, India is irrigated in every part where irrigation is possible.

Outside Madras, private companies for irrigation construction, supply, and management have had no special trial, and in that presidency they have been failures. Bengal, a land almost built up by river silt, for the Ganges alone in a course of 1,200 miles has created a delta 300 miles in width, and lying, too, under an equatorial sun, has a modern public irrigation plant costing some \$28,800,000, serving in 1889-'90 in all some 2,500,000 acres. When the works began in 1870 there were 900,000 acres irrigated in the presidency of Bengal. This included the small as well as large areas. The chief product is rice. The canals now in use, begun as private works, were bought out and finished by the Government some ten years later. The system has several times

demonstrated its capacity to save the native people from the consequences of crop failure. More than that, the insight gained into native affairs and mismanagement by Anglo-Indian officials of the cold, logical type that engineering capacity and experience must produce, has led to the correction of great abuses, such for example as that of rack renting the ryots, under which within fifty years the Zemindars raised the rents from 140 to 290 per cent.

In 1885, in Lower Bengal there were 475,000 acres; in 1889-'90 there were 560,000 acres under cultivation by irrigation. This increase represents about the average increase of such culture throughout India. In the Sone circle the system of works connected with the Ganges and Sone rivers are of an important character. Originally 800,000 acres were brought under them at a cost of \$18,120,000. There were in 1890 1,305,000 acres of rice land served, with a total area of 2,611,000 under ditch. The Ganges system of canals is among the greatest in India. That of the Upper Ganges embraces 890 miles of principal channels, 3,700 of distributaries, 282 of outlet channels, 31 locks, 202 bridges and navigable sideways, with 17 great dams. The system was projected in 1842 and completed in 1884. It serves 1,205,000 acres, and has cost \$14,644,000. The Lower Ganges system embraces 531 miles of main canal, 1,854 of distributaries, 428 of navigable channels, and 56 of escape or overflow cuts. About 620,000 acres are served by this system. The cost has been not less than \$7,000,000.

Bombay in 1889-'90 had 839,000 acres irrigated, and the public capals commanded 915,000 acres. Altogether there were 24,500,000 acres under cultivation in the presidency of Bombay. The irrigated crops in the last-named year were valued at \$1,867,200. The expenditures of the "protective" canals has been \$2,454,400; on the major or "productive" works, \$8,337,600 have been expended, making a total cost of \$10,792,000. Mr. Deakin writes of Bombay that—

A summary of the results of irrigation in Bombay is not to be derived from any merely arithmetical standpoint. The Government is satisfied with the progress made, and the Department is sanguine of yet presenting good balance sheets. Security has certainly been established over large provinces against the suffering, loss, and death which follow in the train of famine. But the changes flowing from it do not depend only upon such contingencies, nor are they remote and anticipatory only. In the old days of Maratha warfare neither life nor property were safe outside village walls, and consequently the trembling ryots herded together in little fortified places for mutual protection. A condition of this kind once established in India has a very good chance of enduring for centuries and receiving at last an almost religious sanction from immemorial use. The Maratha cultivators clustered in their clumsy earth-works for generations after peace was restored. Nothing could have dissolved the practice but a new series of conditions making it the immediate interest of each farmer to get out upon his own soil. Nothing would have distributed them except irrigation, which has accomplished this beneficent change rapidly and peacefully in many parts. A husbandman who irrigates needs to be upon his plot early and late. He must work in it at nighttime in some seasons. In point of fact he must live upon it. By these necessities communities have been dispersed over their fields, to enjoy more freedom, more light, and fresh air, as well as water. A better housed people have been better occupied, better fed, and better clothed, rendered more contented, and in other ways more civilized; the whole of their life has been lifted a little by raising its material base. This has been accomplished under the very eyes of all observers in the present generation by means of irrigation in the Maratha country.

The Bombay code of water laws are rigidly enforced, so that when "water runs upon any land through an illicit breach all those whose farms are benefited are fined in double rates, and if no land is benefited and water is allowed to run to waste, then those to whom the channel is carrying a supply are held jointly liable. These general penalties are, of course, only inflicted when no guilty person or persons can be discovered. Those who benefit by means of a percolation through the

banks, or whose wells are within 200 yards of a canal, are required to pay for the advantage conferred on them without their request. Summary powers are taken for the recovery of arrears." The rules, though severe, are considered just, and generally the penalties are accepted without murmuring.

The canal system of the Panjab and Sind are among the most important and extensive in the empire. The figures alone will establish this. Many ancient works of great size, dating back from the twelfth and thirteenth centuries, are still in partial operation. The British began the work of repair, reconstruction, and new creations as early as 1821, when they took the old Delhi Canal in hand, making modern changes thereon. It was the famine years of 1831-'32 that first aroused them to greater activity. In 1821 this system served only 20,000 acres, while in 1831-'32 it had increased to 94,000. By 1847 \$590,000 had been expended upon it; in 1889-'90, this had reached the sum of \$1,598,400. The West Jumna Canal, which begun as a new work in 1875 to take the place of old and useless channels, has cost up to 1890 \$8,000,000. There are 84 miles of main channels and 1,110 of distributaries, a total of 1,200 miles. The East Jumna Canal was projected in 1830; in 1837-'38, its construction saved \$9,600,000 in crops threatened by drought. By 1889-'90 these two systems had returned the interest on all the expenditures and \$480,000 besides. They had made secure an area of 2,000,000 acres, which paid the Indian Government a land tax or rental of \$96,000,000. A new school of hydraulic engineering has been created by these great works, and the engineers trained in them are the foremost irrigation authorities known to the world. The Doab Canal belongs to this system and section, running parallel with the Jumna River for 450 miles and inclosing an area of 20,000 square miles. The main canals are 130 miles in length and the distributaries 1,112. There are 850,000 acres "under ditch," 590,000 that can be cultivated, and 250,000 that were served in 1889-'90. The total expenditures for irrigation purposes in these provinces represent a British investment of \$36,400,000, and a total irrigated area of about 6,000,000 acres, of which one-half is under regular cultivation each year. These works have for sixty years paid an annual return of at least 8 per cent.

Of other systems the Agra Canal has a total length of of 709 miles, 109 of which are main channels. There are 700,000 acres under ditch, of which total 178,000 acres were cultivated in 1889-'90. The Dun Canal is 75 miles in length, serves 25,000 acres and cost \$277,400. The Rohilkhand Canal has 357 miles of channels and 196,000 are regularly irrigated. The Behar Canal with 500 miles of channel has cost \$1,116,800. It serves 150,000 acres, of which, in 1890, but 24,000 were cultivated. The total expenditures under the British direction, in the Panjab, Swat, Sirhind, Sind, and the sub-Himalayan region, for irrigation purposes has not been less than \$64,000,000. Not less than 2,500 miles of channels were in operation during 1890. In the sub-Himalayan region many private canals have been constructed, which, from the rudeness of the work done, the Government discourages in every way, buying them out whenever it can. All the river channel banks are cut to let the water flow out, a practice which is very wasteful. Rude embankments are thrown up at favorable points to catch the rainfall. It is the practice of these native speculators in water to sell their supply for one quarter of the crops grown under their service. The whole region abounds with wells, usually only rude holes of small depths, protected by brushwood caings. The water is lifted by man and bullock-power and gives from 4,000 to 6,000 gallons each twenty-four hours. The Government off-

cials endeavor to induce the ryots to make new wells and brick up or otherwise improve their old ones. When they do so there is a considerable reduction made in land rent, or other rewards are given. Contrary to the American practice, the Indian engineers prefer water free from silt or deposit generally. They not only like to apply clear water to the land, but they are generally favorable to lifting from stream instead of flooding the water direct from the ditches. Hence serious encouragement is given to systematic irrigation by wells.

It must be borne in mind that the questions waiting solution in connection with irrigation in India embrace many issues far different from those of mere engineering character; they range into the arena of imperial powers, the defense of vast possessions, the security of dependent races, and their training as indispensable factors in a contest for industrial and commercial supremacy. The Anglo-Indian disposition of the ryots or peasants communities determines the character of Indian competition in the food markets of the world, a matter of significance to American farmers. Hence the following account of the policy and procedure adopted in the Panjab and the Sind country, the region of wheat, will have more than a transient interest. Mr. Deakin describes settlement under one canal, as follows:

Under the Sidhni Canal there were 118,000 acres of Crown land, of which 41,000 were capable of being watered. Accordingly in 1886 the problem of securing its occupation faced the Government of the Panjab very seriously, since there was then but one-third of the 64,000 acres irrigable from this scheme in the hands of cultivators. The process of settling an agricultural population upon waste lands hitherto uninhabited, and which can not be cultivated without artificial irrigation, is both difficult and peculiar. In some respects it is analogous to the foundation of a colony, wrote the finance secretary in his letter to the central Government in that year. The returns for 1889-90 show that nearly 64,000 acres were actually watered in the kharif (summer) season, and though 10,000 acres of this received an imperfect supply it is evident that the whole tract has been brought under the plow during three or four years. The same practice has been pursued under the Sirhind system with equal success, while the Chenab and Jhelum projects are avowedly undertaken in order to water large areas of outlying lands, which will require to be settled before the canal supply can be utilized at all. Considering the recess to be dealt with and the prevalent dislike, of the farming castes especially, to leave their districts, the new task imposed upon the officials is by no means simple. They are required to build up from the very rudiments, to settle a population, to attract cultivators, to provide for the foundation and management of villages, to organize and pay the ordinary rural agency, and in fine to establish the whole economy of a new society. The country west of the Satlej at Fazilka was dry, barren, and desolate until the construction of the Lower Sohay canal, since which 50 villages have been created, with over 60,000 acres of watered land among them. In this respect, therefore, the province has undertaken a special and arduous work in connection with its irrigation. It is encouraging to learn that it is being pursued to-day with triumphant success. The annual value of the crops grown on two of the smaller schemes is estimated at upwards of £300,000, reaped from country which a few years before maintained nothing but a few goats and black sheep.

The conditions of settlement differ in minor respects under different canals. The rajbahas, or branch channels, of the Sidhni supply distributaries with an average length of 2 miles, commanding about a mile of country on each side, or about 2,500 acres in all. This is made the village block, but of course the size varies somewhat under other circumstances. Each block under the Sidhni was surveyed into squares of 22.5 acres, and four of these, or 90 acres, was allotted to each settler. This is larger than the usual holding in the province, but was made so to encourage applicants, and also to induce them to undertake the expense of sinking a well and of maintaining cattle to work it, which is only possible in the Panjab for what may be termed well-to-do farmers. A five years' lease was given of each allotment, the charges being 1s. 4d. per acre cultivated, 4s. 6d. per acre watered in spring, and 5s. per acre watered in autumn, with 3d. in the shilling for village officials and local rates. The digging of a well means a reduction of 2s. 4d. a year per acre watered by it for twenty years; 1s. in spring and 1s. 4d. in autumn. The rent for the 90 acres is £1 a year, and the holding can be purchased at 6s. an acre, or £27 for the allotment, after the expiration of the lease. The covenants inserted are something like those attached to the preliminary licences and leases granted to Australian free selectors—no transfer or assignment

is valid without the consent of the department; one-half must be cultivated within three years and two-thirds within four years after possession is given; a proportion of the cost of any irrigation channels constructed has to be paid, and all minerals are reserved. Not only does the State not bind itself to supply any water, but an addition is made in the shape of a declaration that nothing in the deed confers any "right, title, claim, easement, or privilege whatsoever to or in respect of any water," a condition which would be of enormous value to the Australian Governments if it had been inserted in all grants from the early days of the colonies.

In the Indus Valley there are many small canals, each 8 to 16 miles in length, with a total length of 709 miles, supplying water to 214,000 acres, which area was under cultivation in 1889-'90. Three other important perennial canals supply in all 411,000 acres, and have a total length in channels of 1,479 miles. The Lahore branch of the Bari Doab Canal irrigates 523,000 acres at a cost of \$1.60 per acre and a duty of 243 acres each second. It supplies, also, the water needed by 1,352 villages. The cost of these works by 1889-'90 reached a total of \$7,872,000. The year's net proceeds of the water supply to the administration was \$873,600, while the expenditures were but \$288,000.

In the province of Orissa, with an area of 24,000 square miles and a population of 4,250,000, there are hundreds of miles of irrigation ditches, and 250,000 acres under cultivation from them. In 1889-1890, 511,000 acres were under the canal system and ready for cultivation. In 1866, there were but 60,000 acres available. The rivers of Orissa are affected by perennial floods, the effect of which is felt in the natural subirrigation of about 3,000,000 acres.

The independent or native states of India afford to the observer and student problems in irrigation of a most interesting character. They comprise two-thirds of the peninsula, and offer every type of industrial condition from the advanced state of Mysore to the semi-savagery of the fighting hill men. From the point of irrigation and agricultural activity Jaipur is the most advanced. It contains an area of 14,463 square miles and a population of 2,500,000. There are 108 separate systems of irrigation works, having 364 miles of main canals and 422 of distributaries; in all 786 miles. There are five storage reservoirs, the largest of which covers an area of 6½ square miles. The cost of these modern works has been \$1,516,800, and the revenue for 1889-90 was \$140,080. In addition to these new constructions the administration of Jaipur has restored and improved 300 native or village tanks, serving 30,000 acres, at a cost of \$720,000, upon which the return is at least 4 per cent.

In the native state of Mysore there are 1,000 miles of irrigation canals, main and distributing, with 20,000 village tanks. The little state of Kotah has one well constructed canal system, having an extent of 180 miles and serving 50,000 acres. But the greatest proposition of irrigation work in upper India is accomplished by other means than those of canals. There are many thousand rain-fed tanks and wells, small diversions, and temporary dams, with a large number of petty storage areas, made from interior streams and sudden showers. It is impossible to obtain the statistics of these native works; even under the imperial administration the returns are very imperfect. In the more advanced native states there is a systematic encouragement of small works. When built by the state for the ryots, they are required to pay annually a fixed assessment. Remissions are made when seasons have been bad, but with far less liberality than under the imperial rule.

Without doubt the notable features of British Indian irrigation administration are: (1) The large and systematic extension of state aid; (2) the favorable policy on land and water management adopted of late years to aid the peasant or ryot population; (3) the thorough and



costly character of works in certain commanding areas of agricultural activity; and (4) the active and comprehensive manner in which the Anglo-Indian authorities and engineers are aiding in reconstructing the native and village systems of irrigation by means of wells, tanks, and other small, but independent appliances. It will be impossible to make more than a reasonable guess at the extent of the phreatic irrigation appliances in British and native India; still it will not overstep probable limits, but indeed be well within them, to estimate that at least 300,000 shallow wells are used on the Indian peninsula for the purpose of irrigation and cultivation; allowing 20 acres per well this will give 6,000,000 acres as under cultivation thereby. It is in all probability nearly double that area. The following partial table of returns found in Indian water-supply reports illustrates this statement:

Name of district.	Number of wells.	Irrigated land.
		<i>Acres.</i>
Gujarat district	8,195	163,918
Gondaspur district	5,000	100,000
Kandesh district	9,690	193,800
Ludhiana district	1,157	23,148
Madras presidency	85,000	1,700,000
Malabar district	15,178	303,573
Meerut district	14,569	291,395
Monghyr district	3,580	70,000
Nellore district	671	13,420
Punjab district	50,000	1,000,000
Umbala district	3,287	65,741
Total	196,227	3,924,563

A serious effort has been made to obtain a correct statement of British investments in Indian irrigation and reclamation works, but it is not claimed to be a success owing to the difficulty of separating with accuracy the several aspects and items of the great accounts that are involved. But taking only the stated construction items, a total of \$165,956,560 is obtained. The total area of cultivation under irrigation in the imperial provinces is not less than 25,000,000 acres. With the irrigated areas of the native states, which, large or small as they may be, will aggregate 8,000,000, we shall have a total irrigated area of 33,000,000 acres. This estimate is given upon the basis of one crop per year and can be considerably increased if credit be given for "rabi" or winter cultivation. In any event the policy adopted is comprehensively great in its magnitude, and the results achieved are massively great.

The area under wheat as affected by irrigation is a matter for serious examination. According to Prof. Wallace, of the University of Edinburgh, who is considered an authority, there are at least 30,000,000 acres under wheat, of which 20,000,000 are in the provinces, while the remaining third are found in the native states. Prof. Wallace states that in his opinion at least 80,000,000 more acres may be reclaimed, and Mr. Alfred Deakin writes in the Melbourne Age:

There are some millions of acres still available for wheat growing by dry farming in Central India, only waiting for population and railways to become largely productive. Both these wants are likely to be satisfied. The people will steadily flow to them from the many congested villages of the northwest, and the enterprising Government of India shows no signs of relaxing its spirited policy of railway construction, so that a gradual increase in the production from this quarter may be looked to for years to come.

The wheat area affected favorably by irrigation is not less than 15,000,000 acres. Mr. Deakin continues by saying:

Without taking into account what the natives may be able to add by means of new wells and tanks, it is certain that the Government schemes will increase the extent of the wetted lands considerably within the next ten years. There are 10,000,000 acres under wheat in the Punjab and northwest to-day, while the new schemes in the former and the great Sarda project in the latter will probably add another 3,000,000 acres to the irrigated area. The regularity and largeness of the yield from these lands makes them a formidable addition to the Indian total. There is also a considerable acreage watered in which wheat is not yet grown, but upon which it would be grown at once if prices were sufficiently tempting. In the two provinces mentioned the possibilities of wheat are limited only by the possibilities of irrigation. Probably a considerable portion of the uncultivated acreage elsewhere would require a system of water supply to make it permanently productive. The construction of the required works will demand time as well as money, and probably not more than 5,000,000 acres, counting Government and native schemes together, is likely to be added during the present generation to the irrigated area available for wheat.

It is evident from all statements and estimates that the policy of the Anglo-Indian, especially from the standpoint of irrigation security, is one that will need to be seriously reckoned within the food markets of the world.

THE ISLAND OF CEYLON.

The government of Ceylon, beginning in 1875, a practical work of irrigation restoration, has wisely as well as of necessity adopted some of the ancient systems of works and water usages. The irrigation problem has become therefore a very interesting one. As in British India the government is really the chief, or, according to Judge Stephens, the only landowner. In this the British rulers are following the general economic law that underlies all Asiatic and ancient civilizations. It is the opinion of many close students of economic science in connection with general history that a large proportion of the disorder and conflict that has arisen in Asiatic countries which have passed under European control is often the result of unwise because ignorant attempts to remold primary and institutional forces like the ryot or peasant control of the soil under general law or custom, into conditions more like those of landlord and tenants, such as in Europe, and especially in Great Britain, are in operation. British India has suffered greatly from a failure to recognize the fact that the Zemindar class created by Mohammedan conquerors, were not landowners or landlords in the English sense, but collectors from the ryots of the land tax required by all native governments. The more recent and systematic recognition of these ancient relations to the land combined with the vast system of the public works, and especially of irrigation enterprises designed as a protection against famine, tends rapidly and very greatly to strengthen the British administration of India by making it industrial, ameliorative, and beneficial. As India is one of our most formidable competitors in the agricultural markets of Europe, it is well to understand the forces that go to make security there. Another peculiarity which, as it is identical with irrigation works and their maintenance, deserves mention. It is the old system of enforced labor modified and controlled as a local necessity. Of course money or currency, as we understand the terms, has never been of potential force in Asiatic or other countries whose wealth is fixed and immobile in character. If Hindoo or other Asiatic communes or villages have had work to do for the public benefit, they do not as a rule collect taxes and hire labor. They employed themselves to do the work needed, and the government is com-

pelled to offset this against other dues of produce or money. In this way the "corvee" system survives and can not be effaced. As much as British officials dislike it, they have been compelled to recognize the same, especially in Ceylon, the Panjab, Ouhd, and elsewhere in Hindostan, while leaving the village communities to be benefited to regulate the service themselves. We can see a "survival" of this practice in New Mexico. The Mexican irrigationists are everywhere hostile to the creation of new and better systems of works, as is proposed for example in the Mesilla Valley, because the American organizers propose to substitute a small annual payment of \$1 or more per acre in place of the three days' labor generally given per year under the call of the majordomo or water master for the repair of "zanja's" and "acequias."

The Ceylon authorities, availing themselves of such native customs, have for some years past been doing excellent work in the way of reorganizing and enlarging the irrigation system of that island. In one of a series of valuable papers prepared by the Hon. Alfred Deakin, M. P., of Victoria, and published during the year 1891 in the Melbourne Age, there is a full account of the course adopted. The task of the central board is declared by him to be one of no early or easy fulfillment, and he quotes their object as stated in a board report:

It is to the gradual and patient renewal of the ancient irrigation systems of a whole district, utilizing every drop of water available that our efforts should be directed. It is by this means that the crops of a district are multiplied many fold and secured from failure; that many forms of disease and extreme want are banished; and that the health, wealth, and comfort of the people are permanently assured.

Mr. Deakin states that—

Every village in the island had possessed for centuries a kind of assembly of notables and elders, to whom all questions of common interest were referred. The absolute necessity for joint effort in connection with irrigation had been felt, and at a remote period a complete system of administration had sprung up, of which the tradition remained where the works had been destroyed, and the practice where they were still in existence. All land holders were compelled to do their share of repair or else they were refused water. They were forbidden to irrigate fresh fields unless there was a surplus available, and in a season of drought were allotted only a fair proportion of the diminished stream. The rotation of watering and the order of supply were strictly determined, and thefts of water or breaches of custom promptly punished. This communal system was readily revived when the need arose.

It is also noteworthy that the governor, Lord Grey, who from 1846 to 1857 seriously began the consideration of irrigation restoration in Ceylon, also suggested the idea of municipal district organization with local responsibility and the direct bearing of cost by the individuals to be benefited by water storage and distributory work. Substantially Lord Grey's recommendations proceeded and embodied the same ideas and principles that have since been established, with modification of scope, details, and plans, in Cape Colony, South Africa, in Ceylon itself, in California (by the Wright district laws), in Victoria and New South Wales, and later still in whole or part in the States of Nevada, Washington, Kansas, and South Dakota. The Ceylon policy is more conservative than that of the South African and Australian colonies, or of British India, so far as state aid by loan or gift direct is concerned. It is not of course as radical or thorough, in the sense of local self-government, as the municipal district system of California, but it is very simple and efficient. As has already been shown irrigation works in Ceylon, are very ancient, some still in partial use, being dated back to 500 B. C. They are also very complete, existing throughout the island, except in the central mountain district. The Mohammedan rulers in the middle

centuries of the Christian era enlarged them greatly. The later Portuguese conquerors neglected them entirely, and the Dutch mismanaged them. The British began to repair them in a desultory way at the beginning of the present century. For the last thirty years they have worked to great advantage, as may be seen by the fact that the population, which was but 750,000 persons when their rule began, now numbers over 5,000,000. In 1857, Governor Sir William Ward, revived the ancient communal custom of obtaining and regulating water supply. The nature of the works required and their management were to be decided upon by a two-thirds vote of the landowners or farmers in any proposed district. This plan was extended in two periods of five years each over the rice plantations. In 1867 Governor Sir Hercules Robinson, carried a measure which provided for a vote of the landowners for and against the establishment of irrigation districts, and for their control by village council or headmen under by-laws supported when established by penalties. Most important was the authorization of a money advance by the state for expenditure upon private lands. Expenditures for minor works were locally authorized to the amount in each case of about \$500. In larger works, requiring combination, the farmers can borrow from the government without interest on ten years' time, to be repaid by 10 per cent installments. Up to date (1890) the amount of such loans have been £543,000 or about \$2,606,400 (\$4.80 per pound). In 1881, the village or landowner control was modified by ordinance so as to provide for a central board and for provincial bodies of government officers and native landowners. In deciding on local works and regulations, the votes of two-thirds of all farmers owning or renting land and representing one-third of the area to be irrigated, or the votes of those owning two-thirds of the acres to be irrigated without regard to the number of persons, are necessary to settle conditions and secure loans. In the construction of works, always under government engineers, the exact cost, not the estimated, is charged against the community. In preparing plans, £250 may be expended by provincial boards. If a larger sum is required, the matter is referred to the central board. The funds appropriated are equitably assigned among the provinces. If the farmers, as has been found advantageous in many cases, are willing to perform the whole or part of the work required, they are granted certain offsets in payment. Land may be acquired as compensation. The government will maintain all irrigation works, at a cost of about 5 cents per acre per year. A perpetual maintenance can be had by a payment not to exceed 24 cents per acre. The government loan is a first charge on all lands, and the same can be sold if the farmer is in default. It may be borne in mind, in considering the financial side of this policy, that the British authorities collect rent for the land and excise duty on rice, so that the great increase in revenue in both directions that has already arisen from the security in crops derived by irrigation works and management, is more than ample compensation for the non-interest loans that have been made. The works restored and repaired are principally to serve the rice or paddy fields. A considerable area has also been added in coffee, cinnamon, tea, fruit, and other crops.

The extent of the ancient irrigation may be realized by the statement that the British authorities have already restored (1891) 2,250 small and 59 large tanks or reservoirs; they have also constructed 245 weirs or "anicuts," as the Indian engineers call them, with 700 miles of main canals. The several areas reclaimed range from a few hundred up to 10,000, 23,000, and 25,000 acres in extent. The restoration now planned

in Ceylon will it is estimated cost £500,000. There are over 5,000 ancient reservoirs in the island, some of them of immense capacity. One king in the twelfth century is credited with having constructed 4,770 tanks and 543 great canals; also repairing 1,395 large reservoirs, 960 small ones, and 3,621 canals. No snow falls in Ceylon. The rain fall on the coast is 88.85 inches; on the low areas back of it, where the principal crops are raised, it is 23 inches, and on the mountains the fall is 217 inches per annum. This statement is based on an average of nine years. The duty of water is low, as rice is a thirsty crop, and the cost is put for the paddy fields at \$24 per acre. The revenue derived from the irrigated areas in rents, etc., is stated at \$1,500,000. The annual land taxation is £500,000, of which rice pays three-fifths. The total area under irrigation works is given by the Government at 574,000 acres, and by Ferguson's hand book at 700,000 acres.

The origin of the tank system is lost in the impenetrable mystery which obscures the history of the Asiatic races; but the evidences of their antiquity are presented in the solid masonry and concrete of ages. The village tank is only second to the temple in every East Indian village, and its waters are preserved with as much care as the idols; for indeed it is wholly necessary for the health and the sustenance of the people, as well as for the celebration of their religious rites. Commencing in Ceylon, we find the tank system in a fair state of preservation. The laws governing that system in India are necessarily communal, and all the natives who use the water are bound to contribute to its production and preservation. These village tanks are found by the score of thousands in every province or dependency of the British Indian Empire. The report of the Ceylon Central Irrigation Board for 1888 has an interesting account of the system in that island, from which the following extract is made, with a plan showing mode of distribution:

The village tank, however, was the most ordinary form of water storage, and although there were more or less important differences in the mode of making use of its supply, and of apportioning the fields under it, there was a general resemblance on these points throughout the island, and the diagram on the opposite page of the arrangements for cultivation under a tank in the north central province, where ancient customs have perhaps been preserved with less alteration than in any other part of Ceylon, will give a fair general idea of similar arrangements throughout the island.

The general customs according to which land under an irrigation channel in Uva were worked have been described by Mr. Bailey, from whose report it appears that all holding land benefited were bound to take an equal share in the repairs of the irrigation channel. Each proprietor was responsible for the proper repair of a certain portion of the channel, and sudden and unforeseen accidents were repaired by the joint labor of all, as was also the dam, or, in the case of a tank, the bund. No person was entitled to water if he neglected to contribute to the repairs of the dam or channel, and no new land could be cultivated to the detriment of the existing fields. The fields at the end of the channel were plowed first, and the rest upwards in regular order; and if the lowest fields were not plowed at the proper season they lost their right to priority of water. During the dry season the fields were irrigated by rotation, commencing with those at the commencement of the channel (or nearest the bund, as the case might be). When the volume of any supplying stream was insufficient for the irrigation of all the lands dependent on it, they were divided into portions of such extent as would admit of each being properly irrigated, and these portions received the whole volume of the water during succeeding seasons in rotation. The channel was inspected daily, and if any field were found irrigated out of its proper rotation the proprietor was held guilty of theft of water. Any violation of these regulations was promptly punished by whipping or fine, and if a royal prison was at hand, by imprisonment also.

Wana (spill)

Wewa (the Tank)

Herenna
(Spill)

Wana (spill)

We Kanda (Bund)

The fields next
the tank are called
Purampota, or *Mul-
pota*, or *Upayapota*.

The Pote Range

The Pote Range

The Pote Range

The Pote Range

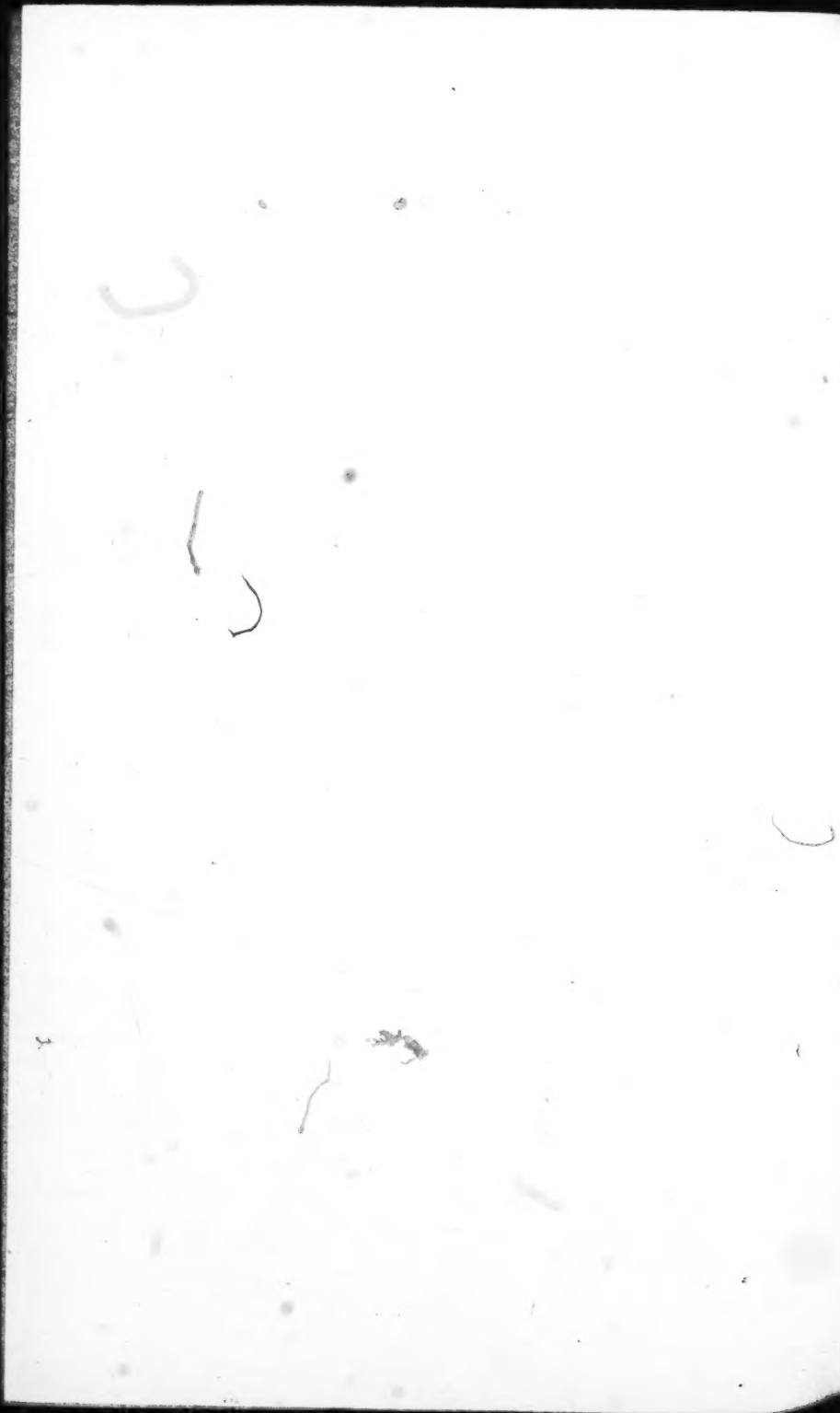
The next range is
called the *Herenna-
pota* or *Peralapota*.

The land opened
in addition to the
above two ranges is
called *Katta Ka-
duwa* or *Alut
Aswedduma*.

KURULLA PALUWA	
INALA ELAPATA	
1	SANWASANA
2	ELAPAT PANGUWA
3	PANGUWA
4	"
5	"
6	"
7	"
8	"
9	"
10	"
1	PANGUWA
2	"
3	"
4	"
5	"
6	"
7	"
8	"
9	"
10	"
PANALA ELAPATA	
KURULLA PALUWA	

KURULLA PALUWA	
INALA ELAPATA	
1	PANGUWA
2	"
3	"
4	"
5	"
6	"
7	"
8	"
9	"
10	"
1	PANGUWA
2	"
3	"
4	"
5	"
6	"
7	"
8	"
9	"
10	"
PANALA ELAPATA	
KURULLA PALUWA	

KURULLA PALUWA	
INALA ELAPATA	
1	PANGUWA
2	"
3	"
4	"
5	"
6	"
7	"
8	"
9	"
10	"
PANALA ELAPATA	
KURULLA PALUWA	



THE AUSTRALIAN COLONIES.

The government of New South Wales expended up to 1890, \$389,320, for the improvement of the Darling River; in order to utilize the same for both irrigation and navigation.* The Murray River improvements have been conducted chiefly by the Colonies of Victoria and South Australia. On all the important western rivers of New South Wales, the late Consul Griffin writes that—

Irrigation is carried on by pumping, and for this purpose centrifugal pumps are used almost exclusively. The engines for working them vary from 8 to 10 horse power, and at one place the engines used are of 80 horse power. In nearly all cases the water is distributed in earthen channels excavated with plows and scops.

H. G. Kinney, C. E. and government engineer for New South Wales, estimates the water available in the Murray basin for that colony at a service of 800,000 acres. The supply from the Murrumbidgee is estimated at 500 acres, making a total of 1,350 acres to be irrigated in New South Wales by the two rivers. Making deductions for use in other ways—domestic and stock—the irrigation area is placed at 1,080,000 acres. The annual rates for water rental are put at from \$2.44 to \$4.87 per acre. An extensive canal projects known as the Murrumbidgee Southern Canal System, is under consideration. It will embrace six main lines and three branches, with the use of Urania Lake as a reservoir. The main distributories will have a total length of 838 miles, and the cost is estimated at \$6,669,746. Mr. McKinney's plans for the utilization of the Murray embrace a canal system of 240 miles in six divisions, at a total cost of \$7,863,535.

The colony of New South Wales has not passed as yet (1890) any of the comprehensive legislative bills proposed by the royal water commission of 1888. All river and stream dams in the colony exist by sufferance only. As a result, when cut, as they sometimes are, by parties living below them, there is no legal means of redress or of deciding issues.

In Queensland the supply and conservation of water is being developed most directly by the systematic use of the drill in boring for artesian water. The "water supply" department of the colony has pushed work in a most energetic manner. J. B. Henderson, C. E., who is the government hydraulic engineer, in his report under date of Brisbane, September 23, 1891, says that—

In selecting sites for artesian wells, one object aimed at has been to test the water-bearing capacities of as large an area of the colony as possible; the bores completed and in progress have therefore been placed in what are considered the most favorable positions for this purpose.

He adds that "marked success" has attended these efforts; that they have created much general interest in "water conservation," and in the scientific and practical questions involved, and that they have been helpful in the encouragement of private enterprise and investment in the same direction. In these respects the "artesian investigation" and "irrigation inquiry" ordered by the Fifty-first Congress have caused the duplication of this Australian experience.

Since such drilling for artesian water begun under colonial authority fifteen bores have been sunk by the Queensland department of water supply, each averaging 1,571 feet, and only one can be called a failure, according to Engineer Henderson's report. Three of the fifteen have been abandoned by the contractors. If their work had been completed no doubt is felt but that an artesian flow would have been tapped.

* Special Report on Foreign Canals and Irrigation, State Department, p. 72.

The total amount of expenditure up to June 30, 1891, is given by Mr. Henderson at \$1,246,959. The amount appropriated for "water storage, main roads, and artesian wells" is given at \$1,713,600. Of the total expenditures all but \$396,519 is credited to direct cost of water supply. There are 33 artesian or well bores named, 3 other wells, 25 tanks and dams combined, one each of overshot dam, tank, and water supply, water hole, trial shaft, and bore shaft. In all there are 77 works under Government control. The greater proportion of these works are of course used for watering stock, some irrigation is accomplished by the artesian water, and domestic service is obtained in several cases. The total number of Government artesian well bores is 15, of which 8 are flowing. The amount of flow runs from 8,228 to 3,000,000 gallons per 24 hours. The 8 public wells in use flow a total of 4,613,428 gallons per diem. The depth of well bores made runs from 323 to 3,262 feet. There are seven ranging from 1,002 up to 1,781½ feet, and three whose depths range from 2,000 up to 2,512. The railway service (Government) have bored one well with artesian flow. The temperature of the water ranges from 77° to 124°, and the surface pressure from 5 to 185 pounds per square inch. There are eighty-six successful private bores or artesian flows. These wells seem more generally successful than the Government operations. No failures are reported. Eleven are reported as "rising in bore," three having "only a very slight surface flow," and of several it is stated, "no particulars to hand."

These are pumped up at depths of from 12 to 70 feet. In three cases water struck in bores was from 1,900 to over 2,000 feet from the surface. There were, at the close of June, 1891, sixteen artesian (private) bores in progress of drilling and twenty-five proposed. The map shows eight successful (Government) artesian wells, two as in successful progress, and twelve as in various stages.

The regulations for watering cattle, etc., at the public wells or supply stations provide as follows: Charge for horses, 3 cents per head; cattle, 2 cents; sheep, 50, 12 cents; 100, 18 cents; each additional 100, the same. The extra amount charged must be paid by the person in charge of the animals. Drivers are given a traveling permit for use on the public stock road, and the caretaker at watering station may refuse water unless the stock has traveled for sixty hours after one watering.

The area to be served by irrigation works in progress in Victoria is about 500,000 acres. The amount of money loaned to irrigation trusts is about \$7,000,000. The area actually cultivated will not exceed 30,000 acres. In New South Wales the amount irrigated in small parcels, such as gardens and orchards, will not exceed 3,000 acres. Provision is now being made under Government aid for 38,000 acres. The plans of the Government engineer, Mr. McKinney, cover a great area, and will embrace 1,000,000 acres.

In South Australia the colony being organized on the Murray River by the Chaffey Brothers, under convention with the Colonial Government, is designed for the ultimate reclamation of some 200,000 acres. There are probably 5,000 acres in the colony now under cultivation by irrigation. Some effort has been made in the direction of boring for artesian water, but without success now or any great promise for the future. This statement is made on the authority of Mr. Edward William Hawker, of Adelaide, who has recently visited the United States as commissioner for the colony on irrigation and water conservancy.

CAPE COLONY.

The water courses of South Africa are cousins german to a majority of those in our own arid region. They are for a large portion of the year dry-stream beds, but like our own streams rapidly assume a torrential character during the rainy or snow melting season. In Africa it is wholly rainfall, however. The physical aspects of the interior are not unlike much of our southwestern sections—high table-lands and mountain plateaus, treeless to a large extent, and almost constantly subject to drought.

Irrigation has been primitive, and sporadic and individual in character, where practiced in Cape Colony, among the Boers, the Free Orange State, and the South African Republic. In 1877 the Colonial Government organized a district system as follows:

Any three or more landowners, with a given area where it is proposed to store water for irrigation purposes, may petition for the proclaiming of such irrigation as an irrigation district. The petitioners must own not less than one-tenth of the land to be embraced. A Government engineer is then sent to attend a landowners' meeting and report to the governor on its practicability. If favorable, the district is permitted. The landowners then choose a board of management, which is invested with corporate powers. Each \$2,500 in land value is represented by one vote. This board has the charge and conservation of all natural waters that rise and flow over or by their nature are common to two or more owners. They have the absolute control of all waters artificially stored and distributed, are given full power to do all the work and construction necessary for the highest use, with the legal right to levy taxes, etc. Land not improved nor irrigated by the district works or supplies shall not be so taxed. The board may borrow either from private means or public funds. In the latter case the loan may be to the extent of one-half of the land value within the district. Public money may be loaned for irrigation improvements to private landowners under due forms of law, to be a preferred charge on their land at 8 per cent for the term of four years. Mortgagees may join in the application, etc. There are provisions regulating appropriations, arbitration, pollution, or obstruction of flow. Another law, passed in 1879, provides for irrigation loans to municipal bodies. Another and more favorable act was passed in 1880. By this legislation the Cape Colony became the first community to adopt the modern system of irrigation districts, as municipal and land owning or communities, formed to own, control, construct, use, and manage waterworks. Scientific surveys inquiries are now in progress for the determination of storage sites and their relations to water supplies. Irrigation is everywhere a success, so far as it is now in operation. Borings for water have not been attempted to any large extent, but success has attended all efforts made, and public interest is aroused in the possibility of phreatic supplies. United States Consul George F. Hollis, of Cape Town, says, under date of 1889:

The most complete storage work completed in this colony and the most important is that at Van Wyks Vley. The rainfall in this section is very irregular, the average for eleven years having been 10 inches, and in some years falling to 3 and 4 inches. The reservoir has depended on the catchment area of, say, 240 square miles. This has been found to be insufficient, and a furrow is now nearly completed through which the water of a neighboring river will be brought in, by which it is estimated that the water-covered area will be increased to 19 square miles, with a depth of 27 feet. The land under irrigation is held by the Government, and is leased at a minimum price of 10 shillings per acre. The bailiff in charge has the sole control of the flow of water, and uses his discretion in its supply, some land within the area requiring more water than other portions. Owing to many causes, the chief of which was

ignorance of the character of the land, fostered by the report of interested persons, who declared that the water would be too salt for agricultural purposes and who desired the work should fail and be abandoned, giving them a chance to acquire it, the poorest tenants, assisted by the Government supplying seeds, were alone secured. Their success has, however, been so marvelous that the lands will soon be eagerly sought after. It is estimated that last year 1,300 acres were irrigated, at an expenditure of an inch of water per month from the surface. The rainfall over the whole colony is so irregular that I have taken the subdivisions of the colony for the purpose of comparing, and have summarized the reports from an average of six stations in each district. The rainfall for these districts for the year 1888 was as follows:

No. 1. Cape Peninsula	53.84	No. 7. East Central Karroo	10.15
No. 2. Southwest	32.95	No. 8. Northern Karroo	11.43
No. 3. West Coast	15.18	No. 9. Northern Border	8.84
No. 4. South Coast	33.60	No. 10. Southeast	98.17
No. 5. Southern Karroo	17.59	No. 11. Northeast	20.39
No. 6. West Central Karroo	14.12	No. 12. Transkei	25.00

The topographical features of South Africa are so peculiar that the system answering for one district is not applicable to others, while the rainfall varies greatly as one leaves the coast and ascends to the various table-lands. In general it may be said that the land being almost entirely denuded of trees and bush, the rain is not drunk up by the soil, but runs rapidly over the surface, seeking its natural outlet to the sea, while the evaporation is very great, estimated at 6 feet at Van Wycks Vley, necessitating deep storage basins.*

SUGAR PLANTING AND WATER CONSERVATION IN DEMERARA.

Irrigation is not practiced systematically in British Guiana, according to the report of United States Consul Walthall,† but the storage and conservation of water is thoroughly worked out, and in seasons of drought at least the sugar planter is not without the means of supplying the lack of natural precipitation. The following account of the management of the sugar estates is worth studying by our Louisiana planters:

The average estate in Demerara has from 1,000 to 1,200 acres of cane under cultivation, while the largest estates exceed 2,000 acres.

The area of cultivation on each estate is generally divided into small fields of 10, 15, or 20 acres. The work of planting these areas is only necessary every four years or thereabouts, while the crop is reaped every fourteen months. To plant a large estate with sugar, cultivate it, harvest it, and manufacture it into marketable sugar requires necessarily a comparatively large number of laborers. These are free black natives, Portuguese, and Chinese, although the majority of laborers are from East India, better known as coolies, who are brought out from India as indentured immigrants under a five years contract at the joint expense of the colonial government and the planter in the respective proportions of one-third and two-thirds. This class of labor is counted most profitable. The laborers are divided into gangs known as follows: First, the shovel gang; second, the weeding gang; third, the creole gang, employed to transport plants from field to field, manure, etc. The duties of the weeding gang are performed by the men and of the other two by women and children, the rate of wages being, men, 24 cents (1s.); women, 16 cents (8d.) per day.

The drainage system should be and generally is most complete. The water supply for both navigation and irrigation is obtained from a fresh water canal which runs along the rear. A sluice gate is constructed on the dam of this canal, and when water is required it is opened and the water pours into the trench. The transportation of canes from all parts of the estate, coals from the river and railway depots to the buildings, is done entirely by punts drawn by oxen or mules. The main navigation trench runs from the river up the center of the estate and is intersected at short distances by cross trenches and branch water ways, affording water ways for transporting canes cut at a distance of several miles from the factory to their destination by water. This, and nearly all other estates in Demerara, front on the sea or river, and are a source of constant trouble, anxiety, and expense to the planter, for their dams are frequently bursting, which has been known to do damage to the amount of £10,000 or \$48,000. A sugar estate in complete working order, and with 1,200 acres of cane under cultivation, is worth about \$72,900. The cost of producing a ton of sugar, interest on capital invested alone exempt, is £12 or \$58 to £14 or \$68. First sugar sells at from £19 or \$83 to £20 or \$97 per ton. When the market realizes this price the second sugar, rum, and molasses are regarded as profits.

*Special Consular Report: State Department; canals and irrigation, 1891.

† Ibid., pp. 327, 328.

IRRIGATION IN EGYPT.

Mr. Robert Wallace, F. L. S., F. R. S. E., etc., author of important works on "Rural Economy, Agriculture," and professor of that chair in the University of Edinburgh, Scotland, recently opened his lecture course by an address on Egypt. The professor is a careful student of irrigation problems, and has represented agricultural interests by an official appointment to study the same in this country, India, and Australia. His recent address gives such a clear and succinct account of Egyptian practices and results that extracts are made. Mr. Wallace states that for agricultural observation the best time to visit Egypt is from August to October. He said:

The mighty Nile, already much swollen, continues to grow toward its full flood and full measure of usefulness and wealth to the industrious cultivator; the cotton crop, by far the greatest source of wealth, gradually and by successive stages reaches maturity; the maize or "dura" crop assumes strength and acquires importance both for man and beast; the sugar cane makes the most rapid progress in its bulky and luxuriant growth, and the whole face of the country is alive with the distribution of rich, red Nile waters to the roots of the crops in the ground and to the land being prepared for wheat, barley, beans, "birsem" or Egyptian clover, etc. The division of Egypt is into "Upper" and "Lower." The upper province extends in a north and south direction from the province of Ghizeh, a little to the south of Cairo, to Wady Halfa, and comprises the lower part of the Nile valley, only a few miles wide, where the river has been confined within a narrow course by the barren hills of the African desert. Lower Egypt is represented by the Delta or alluvial plain, which has been aptly described as of triangular or fanlike form, with its apex to the south near Cairo. It continues to expand towards the north until it reaches the Mediterranean Sea, which forms its northern boundary. A few miles south of Cairo the Nile bifurcates and reaches the sea by two channels . . . the Rosetta branch diverging slightly to the west, and the Damietta branch slightly to the east of the direct line of the original northern course of the river. The whole cultivated area of Lower Egypt is traversed by a network of canals for the supply of irrigation water, by which alone the entire area is prevented from becoming a barren desert. Nearly the whole of the Delta is supplied by water from three great trunk canals which take off from the Nile at or above the Great Barrage Dam, which stands at the bifurcation of the river with the object of regulating the supply of water in its period of reduced quantity. The two arms of the river, together with the three great canals and various large subsidiary canals which branch from them, have been spoken of as the veins of the fan, diverging radially as they do from one important point. The land surface falls away from the river banks and from a number of the canals which were at one period branches of the Nile, so that the surface of the country presents a series of depressed natural ridges which facilitate irrigation operations and will in the fullness of time materially aid the perfect drainage of the country. The Delta in the same rough fashion has been divided into a number of irregular zones or belts of very different character, in a direction lying east and west. The first towards the north consists of a line of barren sand banks skirting the coast. The second is formed by a chain of salt lakes, some of which are above and some below sea level, covering an area of upwards of 1,250,000 acres. Zone No. 3, resting on the southern banks of the lakes, consists of salt marshes which, if drained and freed by washing from excess of salt, would produce excellent crops. The fertile belt, the shortest and widest of the series, comes next, and embraces the greater part of the crop-bearing area.

The cultivated land of Egypt proper is usually stated at about 5,000,000 acres, and it is believed that it is possible to extend cultivation in the future to an area variously estimated at from 1,000,000 to 2,000,000 acres.

The population is now given at 5,000,000, and it has been estimated that Egypt once supported 20,000,000 inhabitants. Prof. Wallace says:

There are two distinct systems of irrigation well illustrated in Egypt: first, the old original basin system of Upper Egypt, at one time the prevailing and all but universal system; and second, the canal system begun by Mohammed Ali, and greatly extended and improved by the English engineers since 1882. In the basin system, where it is impossible to carry it on to the best advantage, large quantities of red Nile water are admitted on the land and retained by earth banks for a period of seventy days, until, by excluding air and light, it destroys the weeds, and by depositing the earthy matter held in suspension it "warps" the surface with a layer of fine mud, which manures the land for the succeeding crop. The seed is usually sown on the mud as the water retires, but at times the land is allowed to become somewhat dry, when it is plowed and the seed sown on an artificially prepared seed-bed, as in Europe. No watering is given to the crop during its growth. The improvements in this system are carried out with the object of gaining greater control over the water both as regards admission and escape. Masonry headworks, regulators, and exit sluices have been built so that it is not now necessary, as it was formerly at certain places, to periodically breach the earth bank for the passage of water. In addition to the advantages of extra control and an earlier supply of water, the expense of filling and discharging the basins has been greatly reduced.

The canal system seen in Lower Egypt and on the high lands* along the Nile banks in Upper Egypt is much more elaborate, and involves much greater expense and greater engineering skill. By a series of large arterial canals, associated with a network of distributing canals, the water can be applied to the soil in moderate quantities, which are within control at any period of the growth of the crop. The great advantages of the canal system over the other are, that a greater variety of important crops, such as cotton, can be grown, and when the water is to be had all the year round two and even three crops in place of one can be taken in a year from the same land. Less water is required per crop; but canal irrigation, involving the use of clear water and for some crops especially a much limited amount of red water, does not support the fertility of the soil as basin irrigation does.

"It tends also," says Mr. Wallace, (a statement confirmed from other sources,) "to an accumulation on the surface of alkaline salts. Evaporation is greater where no drainage exists, capillary action draws the phreatic water to the surface, and with it the alkali salts which had sunk, with the application of water to the surface, or were in the soil before." Mr. Wallace holds that from 1 to 2 per cent of such salts are injurious to plant life. In the salt marsh lands of Lower Egypt the proportion is often over 10 per cent. Drainage is the only effective remedy, and with this the Egyptian irrigation department is occupied.

Surface "soakage" and "seepage" washing are employed to correct the alkali. The first requires a large amount of water. Water flowing over the land as in rice culture is to be found of service. Rice is sometimes cultivated on land not too salt for the purpose of washing out the alkali. The professor suggests that moderate areas be banked and ditched, then the water when turned on sinks into the soil, carrying down the salts, which are in a large degree drained off into the open ditches set to relieve the land. This plan is in successful operation on the estate of Drened Pasha, at Kafr-el-Daouar. Rice cultivation will disappear in Egypt under such a system, as other crops are more valuable. Rice is affected by the salts and does not produce sufficient humus for the soil. "Birseem," or clover, will correct the want of decaying vegetable matter, by the turning of two or three crops.

Canal irrigation in Lower Egypt has led to manuring with a special material that is found in the rubbish piles indicating the sites of ancient villages, towns, and cities. These contain the excreta of the millions that have passed away, which in that dry climate have been preserved. It is termed "sabach," and the piles that mark the site of old Cairo, for example, are rapidly being used to enrich the "dura" fields for miles

* These are called "sharaq," which literally means "cracked."

away. The foundations of old villages are also being dug up and used for manure. So also with stable and animal compost and material. The effect of this fertilization is already apparent in increased production.

The crop season of Egypt [continues Prof. Wallace] is divided into three distinct periods: (1) the winter, or "Shitawi"; (2) the summer, or "Sefi"; (3) the autumn, or "Nili," so called because it corresponds to the time when the Nile is in high flood.

During the winter, the cold weather, the various European crops, which thrive best in a temperate climate, as wheat, barley, beans, and clover (birsem), are grown.

In summer those crops grow which require a tropical or semitropical heat and occupy the portion of the land under crop, viz, cotton, sugar, and rice.

The autumn or "Nili" crops are more of the nature of catch crops, and require, as a rule, only some three or four months to mature. In Lower Egypt the chief crop is "dura shami" (maize); in Upper Egypt, "dura beledi" (or millet, *sorgum vulgare*), maize, and "simsim," or sesame, etc. The cotton is by far the best-paying crop, and there is consequently a strong temptation to grow an increased area of it where soil, water, and climate will permit. It is also an exhausting crop, and at the same time a delicate crop, extremely liable to degenerate, to be chilled, and thereby checked and injured, by cold foggy nights, and to be attacked by fungoid and insect parasites. It is frequently found good practice not to grow it oftener than once in three years, to guard against the various dangers mentioned, though in some parts it is grown with comparative success every alternate year. Where it has been grown year after year on the same land for five or six years the results are not at all satisfactory.

Maize is an extremely important crop for the work animals, which are liable to become poor and weak when kept for a long period on "tibbin," or straw, which has been trodden and ground down in the process of thrashing out the grain to a condition resembling soft chaff. If the maize is planted at the proper season, viz, the 21st of July, so that it can secure the full benefit of the early "red water," the thinning, pulled as required, supply an abundance of green food for the work cattle during the busy "Nili" season. In Upper Egypt the thinnings from the millet crop (which much resembles maize in appearance during the early stages of its growth) are used for the same purpose, but as the young plant is extremely poisonous to cattle until it is about twenty days old, or until after the first watering, it is never used till this has been done. It seems to produce a deadly form of "hoven" in ruminating animals, from which horses and donkeys are exempted.

Birsem, or clover (*Trifolium Alexandrinum*), a large growthed plant with a white flower head, is the great winter forage crop of the country. It is, at the same time, the restoring crop, in virtue of the power it possesses in common with other leguminous crops, of making use of the free nitrogen of the air, and leaving in the soil a rich store of combined nitrogen in its abundant root residue. It is not only the safeguard of the Fellah against the worst form of deterioration of his land, but it is an ample means, in its green state, and also preserved as ensilage (for which it has been shown to be admirably suited), whereby the numbers of farm animals of all kinds, including dairy cattle, may be increased where desirable.

An attempt has been made to grow the potato for the early London market. At one place in Upper Egypt a crop of 10 tons per acre was secured, and a price of £7, or \$34, per ton was got for the potatoes in Cairo. Some consignments realized £13, or \$68.18, per ton in London, from which, however, about \$23.30, per ton of expenses had to be deducted. The best land for the purpose, of many varieties of soil tried, proved to be the rich Nile mud of light character, which is covered by the Nile when in flood and annually manured by a silty deposit, the land which, before tobacco culture was prohibited, was used for the growth of that crop.

The rotation of crops practiced by his excellency Rens Pasha, the late prime minister, Mr. Wallace gives as a good example of what a rotation ought to be to yield the best returns:

- (1) Cotton.
- (2) "Birsem" (clover) or "full" (beans) to occupy the ground for five months. The land is afterwards exposed for five months without plowing or watering. This is probably to allow time for the root residue of the leguminous crop to decompose sufficiently to be of use to the next crop. If watered, the process of decay would probably be of a less suitable kind.
- (3) Wheat, which takes five or six months. The land is left without crop for four months, or, if maize is not to be planted, for six months,

a matter which to a large extent depends upon the available supply of manure, as maize can not be successfully grown without it.

(4) "Dura" (maize) follows wheat, or the land is left fallow.

(5) "Birsem" is sown in the bottom of the dura ten to fifteen days before it is cut, when the land has become dry enough after the final watering, or it may be sown subsequent to the removal of the crop, or on empty land, after the fallow, about the 20th of September. In the matter of grains, the quality of Egyptian wheat as to gluten is somewhat low. Barley is of a better quality. Bread is the chief food of the "Fellahs;" also green vegetables and fruits, chiefly the date. In Lower Egypt maize is the chief grain in use for bread; in Upper Egypt it is millet. The wages of agricultural laborers are now 3½ piasters, or not quite 6 cents per day. The largest expenditure of hand labor in irrigation is caused by the level lift, or "shadies," by which water is lifted from the Nile or canals for summer crops. The chief tool is the "fas," a broad, short-handled hoe. The late Mr. Eugene Schuyler sent, as consul-general to Egypt, a valuable report to the State Department, in response to a circular prepared in 1889 by Irrigation Engineer R. J. Hinton, for the Senate special committee on irrigation and reclamation of arid lands, as a guide in the collection of information by the consular and diplomatic agents of the United States. Some of the interesting data furnished by Mr. Schuyler are summarized as follows:

Sedentary population, census 1882.....	6,302,336
Sedentary population to square mile.....	543
Land area:	
Irrigable, Upper Egypt.....	2,400,000
Cultivated, Upper Egypt.....	2,215,000
Irrigable, Upper Fayoum Basin.....	280,000
Cultivated, Upper Fayoum Basin.....	220,000
Irrigable, Lower Egypt.....	4,000,000
Cultivated, Lower Egypt.....	2,740,000
Total:	
Irrigable.....	6,680,000
Cultivated.....	5,175,000

	Annual rainfall.	Evaporation.	
		Per day.	Per year.
Upper Egypt.....	Inches. 1.050	Inches. 0.197	Ft. In. 71 9
Lower Egypt.....	8.365	0.070	28 0

Slope of Upper Nile, per mile.....	Ft. In. 4 68
Slope of Lower Nile, per mile.....	2 62
Mileage from source in Prince Albert Lake to Mediterranean.....	Miles. 3,187½
From junction of Blue and White Niles at Khartoum.....	1,875
The Nile flood has a velocity at its beginning (per hour).....	1½
The Nile flood has a velocity at its full (per hour).....	3½

Engineer Willcocks in his valuable work (Egyptian Irrigation, 1889) gives the discharges at Cairo and at the Barrage:

Locality.	Channel.	Season.	Discharge in cubic feet per 24 hours.		
			Maximum.	Minimum.	Mean.
Cairo	Main Nile.....	Summer	2,180,948,000	583,000,000	1,200,580,000
Do.....	do.....	Flood	38,450,240,000	18,423,800,000	34,017,680,000
Do.....	do.....	Winter	7,054,000,000	3,178,800,000	4,591,600,000
Barrage.....	Rosetta branch.....	Flood	19,848,840,000	9,536,400,000	13,421,600,000
Do.....	Damietta branch.....	do.....	14,304,516,800	8,298,000,000	8,476,800,000

Estimated mean daily discharge at Cairo, 8,830,000,000 in cubic feet.

Estimated mean annual discharge at Cairo at average of 3,342,668,000,000 in cubic feet.

In Upper Egypt there are 165 basins. They supply and cover 1,462,414 acres. There are also under summer cultivation 461,586 acres; by means of a siphon canal, 291,000 acres: total, 2,216,990 acres.

The system in vogue is a river, with transverse and parallel dikes. There are 21 basin systems, and the water is usually first let into the upper one, then passed into the others, and what is drained back from the lower basin into the river.

For ten years past the average flood variations between highest and lowest gauge has been 9 feet 1 inch. The annual Egyptian Nile rise begins at the end of September. The White Nile reaches its maximum in August. The Blue Nile begins in April its rise on the Abyssinian plateaus. At Assoor, the beginning of Egypt, the maximum flood occurs between August 15 and September 30. It is proposed by the English engineers to construct high-line canals and fill all the basins simultaneously. The total ordinary expenditures for irrigation were given for 1890 at \$2,560,000. Mr. Schuyler wrote that—

There are, however, also extraordinary expenses. In 1885 a decree allowed \$5,000,000 to be spent for the improvement of the irrigation works. Of this there had been spent on December 31, 1888, the sum of \$4,233,075. There will be allotted from a new loan now being negotiated the further sum of \$4,550,000 for the same purpose.

The aims of the Anglo-Indian engineers now and for six years past in charge of Egyptian irrigation works, are thus epitomized by Mr. Willcock:

- (1) The strengthening and securing of the barrages so as to insure a constant high-water level during summer, and not only utilize the whole summer supply of the Nile, but do away with a great part of the heavy silt clearance.
- (2) The construction of escapes and supplementary flood canals, so as to irrigate during summer from the summer canals, and during high Nile from the summer canals in their lower reaches, and supplementary flood canals in the upper reaches of the summer canals, and thus reduce silt deposits.
- (3) Having reduced silt deposits to a manageable amount, to substitute dredging and contract work for the *corvée*.
- (4) The obtaining of flood supplies as early as possible into the flood canals.
- (5) The reduction of regulation of the supplies entering the summer canals during flood so as to save the lowlands from inundation.
- (6) The improvement of the lowlands themselves by drainage and basin irrigation.
- (7) The improvement of the navigation.

The land tenure and water supply practices in Egypt are a very uncertain quantity for the poor man. Lands are leased or rented, are tithe and tributary lands, "nulk" or freehold. The latter is modern in origin. The state is considered, as in India, the real proprietor. The management of irrigation has always been in the hands of the rulers, whoever they may be. Mr. Schuyler says:

According to the existing laws remission of revenue is granted on land incapable of being sown with the winter crops, although flood crops irrigated by lift are ex-

pected to pay the full taxes, but no provision is made for crops destroyed by floods during the inundations, or by drought in summer. Owing to the fact that there is plenty of water when the crops are sown, they are often sown to excess, and as the summer supply of the Nile only suffices for about one-third of the area in lower Egypt in May and June there are very often failures of harvest. All such cases are now decided by the native court and the mixed tribunals on the basis of certain articles in their codes, but these are very insufficient.

Mr. Willcock says:

This not in a country where the Government sells the water, but where the Government performs functions that the atmosphere does in other countries. However, things have become so bad now that something must be done. Previous to 1882 the mudirs or civil governors protected the poor as a rule from Jews and Christians, while the State was strong enough to hold its own. Now the tribunals dominate the State, and are unable to help the poor.

The water-lifting practice is one of the most important in Egypt. It consumes a great proportion of the agricultural labor, all the more so because rude and simple. Lifts less than 40 inches are made by means of the "nattal," a closely woven palm basket with ropes on either side, held by two who stand or sit near the water's edge. They swing this in such a way as to fill it with water and throw it into the mouth of a small ditch, which carries it over the fields. By this process two men can raise from 140 to 175 cubic feet of water per hour. This has the advantage of being easy, inexpensive, and applicable anywhere in proper conditions. When it is necessary to raise the water more than 40 inches this becomes fatiguing, and the "shadoof" is resorted to.

The old well sweep used in this country illustrates this system. The water is taken from small wells dug into Nile banks and filled by the river flow. The work is slow. A man averages only about 10 baskets or 22 gallons a minute, that is, 211.90 cubic feet per hour. The relays of men are changed every two hours. It is estimated that when the bank is sufficiently low to allow of "shadoofs" two men will water an acre and a quarter per day.

Water wheels are in common use, principally the "sakieh" or Persian wheel. Whoever has visited Boise Idaho, has seen such wheels, improved somewhat as to buckets, etc., in operation along the streets. On the Snake River, also, such wheels, very much enlarged, are in general use. One of the Egyptian "sakieh" will irrigate from 5 to 6 acres. The "sakieh" consists simply of a vertical wheel, an endless chain of small earthen pots, placed at about a foot from each other, which descends into a rude well on the bank of the Nile, thus bringing up the water and pouring it out into a trough leading into a canal. This vertical wheel is turned by another horizontal wheel applied to it by a rude system of uneven cogs, itself turned by a cow or a buffalo harnessed to the end of a long lever. The "sakiehs" are sometimes used in wells in the middle of fields, where such exist, and their existence is known at a long distance by the groaning sound produced by the creaking cogs.

There are estimated to be 28,000 "sakiehs" in the delta or Lower Egypt, where the water has to be lifted from the canals for all summer irrigation. The total area therein is stated at 1,235,500 acres.

IRRIGATION IN ASIA.

THE TURKISH PROVINCES.

Irrigation in the Turkish provinces of the Mediterranean, though necessary for the major cultivation, is still carried on under the most primitive forms and conditions. As will be seen from the annexed presentation of the Ottoman code, the control of the water is maintained in the community. Ancient and oriental communities, practicing irrigation, have had the water supply therefor under public control. Where great works were constructed in ancient times they were so made at the expense of the sovereign or State. As in Egypt down to a very recent period, the "*corvée*" or enforced labor prevailed in all irrigation, road-making, or other public works. Even in portions of India the system still prevails under modified forms. Assyria, Babylon, the ancient kingdoms of the Levant, those of North Africa—as Carthage *et al.*—Persia, Ceylon, and the Brahmin, and the Mahommedan and other more ancient rulers of Hindostan have all constructed and possessed great systems of storage and distribution, the engineering skill displayed in which is still the admiration of those who have studied them. Yet the chief results of irrigation cultivation have in all oriental countries been obtained by the small cultivators and the petty and individualized irrigations. These have gone on holding their ground to a large degree under systems of community regulation, and maintaining a considerable amount of agricultural activity, in spite of the historical fact that the great State works, often racial, dynastic, and always imperial in character and extent, have been destroyed during the progress of the tremendous wars, which in the ancient world have destroyed empire after empire, and communities, cities, towns, villages, with all their works, agricultural life, and other industries. Yet the small irrigation has held its place and is found everywhere, even as in Thibet and on the Pamar, at an elevation 12,000 feet above sea level the pivotal fact on which a working life has been sustained, and upon which, with new forces, as in British India and in Russian Central Asia, larger and more sustained development in the modern sense, has been or is being organized into existence. China and Japan are remarkable examples of what can be sustained in the way of industrial civilization by means of the individual farmer, working under simple community rights as to water and its use in cultivation. China and Japan have not in use a single great work, outside the great canal of China, for irrigation supply and distribution; yet the two empires carry on under their primitive but minutely-careful mode of irrigation an agriculture by which at least 300,000,000 persons are directly sustained. In British India at least one-third of the vast population are equally fed from small irrigations, the water for which is obtained from village wells and tanks or small ditches, that have been in use (or are modeled upon those that were) for many centuries. In all cases there are written or unwritten codes, customs and regulations, which recognize the public nature of water and provide for the local or community control thereof. Taking

the populations of other European dependencies, of Persia, Afghanistan, Thibet, Corea, and the native States generally, it will be found that at least 450,000,000 Asiatic persons are dependent for food upon the small irrigations under review.

The Ottoman code or law of water rights, usages, and proprietorship is an excellent example of the principles underlying the community water control system of Asiatic countries. It has already been published in a consular report, but is inserted here as an illustration of an historical condition:

Water, herbs, and fire are things outside commerce; all men enjoy them in common. Water running under ground is the property of no one in particular. Wells not sunk by anyone in particular, and which are used by the public in common, are common property.

Seas and great lakes are common property.

Streams of the public domains, that is to say, those which do not specially belong to anyone, are those whose bed is not the property of a number of persons; such streams are in common, as for example, the Nile, the Euphrates, the Danube, etc.

Private streams, i. e., those whose beds traverse the lands the property of private persons, are of two kinds:

1. Those waters are subdivided among coproprietors, but which do not empty or exhaust themselves completely into the lands of the latter, and which run afterwards into public rivers; such water courses are also designated public because part of them is public domain; the right of preëmption is not applicable to these water courses.

2. Private water courses which run within the limits of the property of a given number of persons, and whose water is exhausted and disappears upon such property without reappearing to form another confluent; preëmption rights are only applicable to such water courses.

Alluvium deposited by a stream on the land of a private individual becomes that person's property; no one else can lay claim to proprietary rights thereto.

Herbs of natural (wild) growth upon lands the property of no one in particular are held in common, the same with herbs that grow upon private property unknown to the owner; but if the latter waters his land or incloses it with a view to prepare it for cultivation, then the herbs growing thereon become his property; no one else can appropriate them, and he who gathers them is held responsible therefor.

By herbs are meant such plants as are not artificially watered; mushrooms, for instance, are included therein, but trees are not.

Trees of natural (wild) growth upon mountains, which have no owners (djibali monbaha), are held in common.

Trees of natural (wild) growth upon the property of anyone belong to the owner of such property; nobody can cut them down without his authorization. He who grafts a tree becomes the proprietor of the shoots and fruit thereof.

If anybody occupies a thing now common he becomes the exclusive proprietor thereof.

Examples: The water which a person draws from a stream with a receptacle becomes his undisputed property, and if a third person consumes it without the owner's permission he is held liable therefor. The occupation of a thing must show intent; consequently, he who has placed a receptacle with the intention of collecting rain water becomes the owner of such water. The same with water accumulated in a basin or cistern; but the rain water found in a receptacle not expressly placed for such a purpose is not the property of the owner of the receptacle, and other persons may appropriate such water.

It is necessary in the occupation of water that it does not run continually; so, for instance, well water, which filters through, is in common. He who consumes the water thus obtained by filtration, even without the proprietor's consent, is not held liable for damages. Again, water is not considered as having been appropriated where as much enters a basin on one side as escapes on the other.

Everyone may enjoy a thing held in common on condition that such enjoyment causes injury to no one.

One can prevent a person from occupying or appropriating such a thing.

[The contestations relative to water courses for drinking or irrigating purposes, and the customs and usages existing from antiquity are only to be taken into consideration.]

Everybody can use the waters of public streams for his lands, and may for this purpose, or for the purpose of constructing a mill, dig canals and ditches or trenches on condition, however, of doing no injury to anyone. Works which cause an inundation, those which completely exhaust a stream or which prevent boats (barges) from floating, are to be interdicted.

Man and beast may drink of the waters not the individual property of any

one. The right to use water for irrigation and for the consumption of animals ("chirb") of water courses not public property belongs to the owners of these streams (courses); any other person, however, may drink therefrom. Thus no other person than the owner can serve himself of the waters belonging to a community or of a ditch, trench, or well, for irrigating purposes, but he may drink therefrom and even water his animals, provided the number of these be not so large as to damage the water course, the canal, ditch, trench, or conduit; he can likewise draw water therefrom with a picher or a pail and carry it to his house or garden.

Those who possess a brook, stream, basin, or well upon their lands whose waters are renewed by nature may prevent anyone who wants to drink therefrom from entering their property; but if there exists no other water in common in the neighborhood the owners are obliged to either offer the use of their water or allow their lands to be penetrated; and in case they fail to offer their water those who wish to drink may enter the property, provided no harm is done thereto by damaging, for example, the edge of the wells or the water conduits.

One of the coproprietors of a common water course can not, without the permission of the others, cut a channel, ditch, trench, or gutter. He can not change his "turn" or share of the enjoyment of the water long established, nor cede such right to a landed proprietor who has no right to the waters of such a river for irrigating his field or watering his cattle.

The authorization to perform these acts given by the other coproprietors could be revoked by these latter or by their heirs.

In all contestations touching drinking water or water for irrigating purposes the rules, regulations, and usages established *ab antiquo* are to be enforced.

The waters of rivers, streams, springs, and other water courses passing through the lands of a village or a city are the property of the community, and must be distributed, as has been the ancient practice, in such a manner as to secure a supply to each landed proprietor during certain hours either weekly or fortnightly. Every owner of land knows the exact time and quantity of water to which he is entitled, and in almost every village there is a civil officer who is charged with the duty of looking after the proper allotment and distribution of the water among all the inhabitants. Time is usually measured by hourglasses.

In Asia Minor, Syria, and Palestine, the sources of supply for irrigation are the small streams, wells, and pools, and the modes of using and distributing are of the simplest character. Olive trees, for example, are seldom watered after the period of growth before bearing. The fig tree is irrigated generally for a limited period each season, by means of the water bag carried by men to each tree and applied directly to the roots. Shallow wells are numerous, and their water is lifted generally by means of a wheel, the flanges of which are also water buckets. A large buffalo skin is made into a bag by cords at the corners, let down into a well, and then drawn up filled with water, which is emptied into a conduit. The power used is generally animal—oxen, asses, or camels. The general plan used is known as the "Na'hura" wheel, clumsy in construction, but raising a considerable quantity of water. It consists of a clumsy cogwheel fitted to an upright post and made to revolve horizontally by an animal attached to the sweep; this turns a similar one perpendicularly placed at the end of a heavy beam which has a large wide drum built over it, directly over the mouth of the well. Over this drum revolve two rough hawsers or thick ropes, often made of myrtle twigs and branches twisted together, and upon them are fastened small earthen jars or wooden buckets. One side descends while the other rises, carrying the small buckets with them; those descending are empty, while the ascending ones are full; and as they pass over the top they discharge into a trough, which conveys the water to the cistern. The length of the hawsers and number of buckets depend upon the profundity of the well; for the buckets are fastened to the hawsers about 2 feet apart. The wells are of different depths, but generally average from 10 to 15 feet. It is claimed that with good animal power a bucket containing about 2 gallons of water can be raised every second.

PALESTINE AND SYRIA.

These still remain irrigation lands, though its extent is now very restricted. The management of the water is crude and primitive in character. Mr. Henry Gilman, United States consul at Jerusalem,* says:

Small fields, gardens, or patches of ground are here and there cultivated in the neighborhood of some stream having its source in one of the perennial springs of the region. From such a spring the water is conveyed in shallow drains or ditches to wherever required, and is carried through the fields or gardens by still smaller channels, the water being shut off or let on simply by the action of the foot, opening the tray inlet, or blocking it up with a few pebbles or masses of clay, as may be desired.

In the scattered and small areas in which cultivation by irrigation is practiced, the Bedouins of Palestine follow the simplest methods. Mr. Schumaker, United States consular agent, says:

In the early morning or shortly before sunset young Bedouins, in a seminude state, may be seen roughly constructing from stones and earth a temporary dam to obstruct the waters of a stream or wadi (valley), while others provided with broad hoes dig little ditches through which they lead the overflowing waters, to be distributed over the parcels it is intended to irrigate, allowing the water free course in the lower lying lands, thus inundating or rather completely setting them under water. These manipulations are of daily repetition; the dams have to be regularly rebuilt, for the pressure of the water causes their daily destruction, and it is interesting to watch with what assiduity and perseverance these Bedouins are continually remaking and renewing the little ditches and canals, which need their unremitting attention.

At Jaffa and in its neighborhood there are about 3,000 acres of oranges, olives, and other fruits, with garden vegetables, under cultivation by irrigation. The value of such exports per annum is about \$300,000 a year. The water is drawn from shallow wells, chiefly by the "vajara," a simple water wheel, of which some 700 are in use. The irrigation season, from May to November, is one hundred and sixty days, and the cost of water will be from 20 to 25 cents per acre; that for the dry period will be at least \$33 per acre. The net yield per acre will not be less than \$150, the exports being valued at \$120 per acre.

In Syria itself works for the utilization of the underflow are quite numerous. They are usually placed on lands lying along the foot of a mountain, from which rivers, springs, streams, or other water courses flow, and which by reason of their gentle slope adapt themselves for irrigating purposes.

At Beirut the irrigation area extends 5 miles in one direction and some 10 in another. Mulberry trees are the most abundant product. In Tripoli the chief orchards are of oranges. The area covers 5 acres square. They are supplied with water from the Lebanon range. There are considerable areas under cultivation by irrigation in northern Syria. Canals or ditches are expressly dug for this purpose where they do not already exist or where the water does not run of itself. The canals are usually old and are not kept in good repair. Springs are carried into cisterns or tanks built of masonry well cemented, which are usually emptied each day. Large reservoirs are unknown, and the maxim among the natives in force is "that irrigation is only profitable where the water runs unaided by man." Their ancestors were of a different opinion, judging from the numerous works left by them scattered broadcast over the land. In modern irrigation and waterworks the Beirut waterworks take the first rank. They are the property of an English stock company, which furnishes an excellent quality of drinking water at fixed rates, as well as a needful supply for irrigation purposes at reasonable charges.

*Special Consular Report on Canals and Irrigation, 1891, p. 342.

Progress is made in three directions. Pulsometer pumps of considerable power have been introduced, and in one instance proved entirely successful, though the water is raised 130 feet. American wind motors are also slowly coming into use. The Mount Lebanon areas are exceptionally well cultivated. Mr. Edward Bissinger, United States consul in Beirut, says:

Irrigation, as has already been shown, is regulated entirely by usage and well-established rules, and every parcel of land has a right to the use of water for certain well fixed length of time; for instance, a small proprietor near Beirut has 5 acres of land; every Friday he can take as much water during six hours as he may need to thoroughly saturate his land; if he fails to take advantage of his privilege he simply forfeits it without being indemnified therefor. Where water is scarce, as in many places in the mountains, it is often divided into hours and even fractions of hours, and good care is taken that no one receives or takes more than his allotted share. The sole owner of a spring, a rare occurrence, however, may of course use the water thereof at his own pleasure.

It is worthy of remark that in Mount Lebanon the waters of every spring, no matter how limited its capacity, is caught up into cisterns of good solid masonry and is utilized for irrigating and domestic purposes, and no matter how steep the mountain sides or how poor the soil, the smallest available tillable space is planted with onions, vegetable marrow, or egg plant, and three and sometimes even four crops are thus produced each year.

Projects and plans of a considerable character are under way or in consideration in Syria and Palestine, and a few years will undoubtedly see a large addition to the cultivated area of both these historic regions.

In Syria there are a number of works of great antiquity; some are in ruins, but others still remain in use. Near Beirut are two aqueducts, built upon arches or cut partly through solid rock. The works at Damascus, Tripoli, Hama, Hamath, Tyre (Solomon's Pools), and other important points, are of great antiquity. The conduits and aqueducts are of stone masonry, earthen pipes, or hollowed out of stones in place or artificially arranged. Beirut is furnished with modern works, constructed by an English company. Reservoirs are unknown. In the valley of the Euphrates and on the Mesopotamia plains there are many ancient works of great extent now largely disused, but which could be availed of if the channels were cleared out and repaired. In Persia, Afghanistan, Turkestan, there is a system of underground conduits called "karnaks," by which phreatic water is conveyed long distances and distributed to fields below the point of debouchement. These "karnaks" are made by digging well holes to the gravel, sand, or boulder stratum in which the drainage water is gathered. They are made a short way apart, beginning generally in some foothill section. When the bottom is reached a conduit or small tunnel is hollowed or dug out from each well. In this wise the water of the saturated stratum is gathered into a stream which flows under ground, until by gravity the water therein flows over the fields below the mouth of the "karnak." The wells or openings are often used as watering places for stock, as well as for domestic purposes. There are many hundred miles of these rude conduits in Persia. They are also in Cashmere, Afghanistan, and other points of Central Asia, where the mountainous topography gives promise of a large supply of phreatic water. English travelers have called attention to the danger attending such conduits in the probable desiccation of areas lying above the route of the conduits. It has been observed by such travelers that grass and other forage perishes along the line of the "karnaks." This is a point worthy of consideration.

Something similar to these devices is described by Mr. N. A. Nahikon, who writes as follows:

The most extensive system in Armenia, is by wells dug in the following way: First a man will take the level of his land, then going up toward the base of the mountain he will have a well dug, generally from 80 to 100 feet deep, which will be a few feet above the level of his land (the bottom of his well I mean); then they dig three other wells between these two points, the depth of the wells diminishing, of course, as they approach the farm. They dig a tunnel through the bottom of all the wells high enough for a man to walk through. This precaution is taken so that, in case there be a cave in of earth, they can open one of the wells (which has simply been roofed over), and a man is lowered down to see what is the matter. The water will flow through this tunnel until it comes to the surface by gravity at the desired place. Here they make a kind of reservoir 40 by 25 feet in size and about 3 or 4 feet deep, taking care that the bottom be not on sandy soil; and then to stop the evaporation of water from the said reservoir, they plant all around it mulberry trees, which, having thick foliage, will almost entirely hide the water from the sun's rays. These reservoirs are generally owned by several persons, and the measure of distribution is by the reservoirful per fortnight. Many persons may not own either any land or water, but may have the trees as property. These waters also during the winter go to waste. In the summer they are awfully cold. Really I know many of them that are too cold to wash hands in or drink at the point where they just come from the ground.

There is not a single perennial stream of water in or near the city of Jerusalem, and only one in its immediate environs. There is a small stream which for a few weeks in winter flows down the Kedron Valley half a mile below the city; there is another ephemeral fountain which gushes forth a few weeks in the winter. Siloam is the only perennial stream about Jerusalem, if indeed that can be called a stream, which is intermittent.

The population of Jerusalem has always been largely and almost entirely dependent on wells of living water.

The winter rain was to the Hebrews what the Nile was to the Egyptians, and every means was adopted to economize the scanty supply. At a distance of 7 miles from the city there were extensive tanks and wells constructed, undoubtedly of the greatest antiquity, the intention of which was to collect water, to be conveyed by conduits carried upon and beneath the surface, and on a due level around the slopes of the country, a distance in its windings of not less than 12 miles. Two of these aqueducts conveyed the water; the one directly to the city near the Jaffa gate, and the other in a circuit around Zion on the southern side to the temple. All writers on Jerusalem who have investigated the water supply attest the fact that, notwithstanding the aridity of the surrounding country, the inhabitants of the city have always had water enough and to spare.

Aristeas, an eye witness, says:

There is a continual supply of water as if there had sprung up an abundant fountain underneath, and there were wonderful and inexpressible receptacles under ground, each one of which had divers pipes by which water came in on every side.

All these were of lead under ground, and much earth was laid upon them, and there were many vents in the pavements not to be seen at all by those who served, so that in a trice all the blood of the sacrifices could be washed away, though it were never so much.

The city of Jerusalem is indebted to Sultan Mahomed for its present supply of fresh water, as the Mahomedans even more than the Jews require an abundant supply of fresh water for their religious observances.

The pool constructed by Solomon, called the "King's Pool," 8 miles from the city—

consists of three enormous reservoirs, partly cut in the rock, partly built of massive marble masonry. Their dimensions are as follows: The upper pool, 380 feet long; breadth at east end, 236 feet; at west end, 229 feet; depth at west end, 25 feet.

The middle pool, which is distant from the upper pool 160 feet, is 248 feet long; it is at east end 250 feet broad and at west end 160 feet, while the depth at east end is 39 feet. The lower pool, 248 feet eastward of the middle pool, has a length of 582 feet; a breadth at east end of 207 feet, and at west end of 148 feet, and a depth at east end of 50 feet. Each pool overflows successively, by regulated sluices, into the next below it, in the order given, the last pool emptying its superabundant water into the valley. The source of the water supply is the Sealed Fountain of Solomon, at the foot of a hill, a short distance west of the Upper Pool. This fountain is always kept locked; hence the name. A flight of twenty steps descends from an arched doorway into an underground vaulted chamber, where four streams of pure and cool water converge.

A small acreage is irrigated from these pools and from that of Siloam. There is a copious spring in use for the valley and village of Urtaa. Consul Gilman says:

The distribution of the water is regulated by the old custom of system of "fassels," a night and a day forming a "fassel." Each family owning land there know, from time immemorial, its respective rights and share in the "fassel" of water. Some have an entire "fassel," and again the same is divided among the different members of a family, to irrigate their respective shares of land. The water is carried from one plat to another by drains in the usual simple manner already described. The Europeans who own land there have made, however, a cemented conduit to convey their share of water into their ground. No statistics are obtainable, none ever having been kept, as to the duty of water per acre. No special rent or fee is paid for the water used, nor are there any charges on the land in connection therewith, the only payments made being the usual government taxes—the "werke" (land taxes) and "ushur" (titles). Solomon's Pools, the Sealed Fountain, and the aqueduct are public property, and are under the control of the Turkish Government.

The temperature of the water at Jerusalem is about an average of 65 degrees. The largest tank or cistern remaining is 376 feet in circuit, is 42 feet deep, and has a capacity of 2,000,000 gallons.

These meager statistics of the water supply of Jerusalem have been given because the city is better known than any other ancient capital, and from the fact that its surrounding desolation and aridity exceeds any part of our Western domain. Our frontiersmen can reasonably take courage by the comparison.

CHINA.

All irrigation in the Empire is conducted practically on a mutual or coöperative plan. The sources of water supply are generally the tributaries of large streams, the latter being made useful for navigation with irrigation as an incidental service. The most minute care is taken to preserve every source of water or other liquid for use in cultivation. In southern and central China it is estimated that 1 acre of cultivated land will support from three to five persons. Rice and vegetables are the chief crops. Wheat, millet, and barley are raised in the northern and far inland provinces. Irrigation processes in southern China are described by Consul Seymour as follows:

Return rows of growing vegetables, trenches filled with water obtained from the creeks, brooks, or pools, are kept; and once or twice a day the water is scooped from these trenches upon the raised ground, in which the roots have great depth of loose and moist soil to promote growth. When these trenches of water are not available, owing to scarcity of water, or to porous land, the men and women carry, suspended from a yoke across their shoulders, two large buckets with long spouts, and sprinkle the rows of vegetables copiously. Sometimes the water for this purpose is carried in buckets a considerable distance. For the irrigation of rice lands, which have to be submerged, the lands are divided into small patches at large levees, so that the appearance is that of a beautiful system of terraces, near a bountiful supply of water, which is raised to the upper level of chain-pump and tread-mill process with cool power. From the upper to the lower levees the water descends so gradually as to avoid washing away the substance or fertility of upper to lower lands.

In Ningpo, Fo-Kien, and Shaughai the modes of irrigation are generally from small ditches, taken from streams or large canals. At

Ningpo the ditches are mainly fed by phreatic waters supplied from springs, which come to the surface in the bordering hills of the valley. The river water being brackish is never used. The supply canals are numerous, from 2 to 3 miles in length, and supplying the shallow laterals, which are dug at right angles, from 200 to 400 feet apart and 10 to 30 feet wide, supplying all the small fields and tiny gardens of the Chinese farmers. In the province of Fo-Kien, as the rainfall is equally distributed and quite heavy, irrigation has become an additional security rather than a primary necessity. There are no storage dams, though the country is well adapted to their construction. Consul Campbell, of Fuchan, says:

The water used for irrigation is drawn up from the ponds and water courses by an endless chain or rather an endless rope pump, which is worked by one man or sometimes two men by treading upon a wheel made with a number of radiating arms which causes the wheel to turn upon its axis. A horizontal pole about 5 feet above the shaft is made fast, and the men support themselves by leaning upon this pole by treading the wheel. One end of the box through which the chain draws the buckets is placed in the water at an angle of about 45 degrees with the pond, river, or canal from whence the water is drawn into the field. The box is open at both ends and is made strong and light. The whole apparatus is easily carried by one man on his shoulders. The faster the man treads the wheel the more water is pumped, and the machine is kept going night and day when water is needed for irrigation. The pump is run very much on the principle of the treadmill so far as the motor power goes, and the water is carried up with the buckets something like wheat is raised in an elevator. * * *

Water is conducted into the fields, which are usually marked off into small compartments according to the number of proprietors by earth embankments, the water filling one after another until all are covered. Everything is carried by human beings on their backs. The vegetable garden, flowers, and small plants are watered by water carried on the backs of the laboring people—men, women, and children.

There are no written codes or laws; custom, handed down from immemorial time, rules everything. According to the latest idea of the ethnologists and historical students, the Chinese, in irrigation and other things, derive their methods from Assyria and Babylon, as they are considered to be descended from the most ancient Turanian stock, whose existence on the plains of Mesopotamia is regarded as indisputable. The processes indicated are general throughout China, while on all sides and by every ingenious primitive process that can be devised the most economy in storage and the largest duty of water in distribution is daily obtained. There is a recent increase of interest arising, owing, probably, to the fact that so many Chinamen have seen irrigation of late years in other countries and under different conditions. Quite recently the office of irrigation inquiry has received a request from an English engineer in the service of the Imperial Government and stationed in Yunnan, the province lying next to Annam and Burmah, asking for information relative to artesian waters and wells, he being about to commence boring experiments.

Recent speculation on the racial origin of the Chinese, attributing their civilization and policy to a migration from Babylonia and Assyria, seems to receive a contradiction in the nature of the agriculture, canal, and irrigation works. The latter, at least, were of a much larger and more important character in the valleys and plains of the Euphrates than is anywhere to be seen in China. The navigable canals in the provinces accessible to commercial and other outside intercourse are all used as sources of supply for the irrigation ditches and laterals. United States Consul Pettus, of Ningpo,* says:

At Hangchow the canals of this district connect with the Grand Canal, which leads as far as Peking. Almost every farm in this district has its canals for transportation and irrigation.

* Special report on "Canals and irrigation," State Department, 1891, pp. 64, 65.

Branch canals are excavated from the main canals at short distances, from 100 to 300 yards. These canals run at right angles from the main arteries, so that all the farms and gardens can be irrigated, which is done by wooden chain pumps made to reach the water from the bank. They are worked by hand or ox. So all farms in the valley are irrigated, always insuring a good crop of rice.

The lifting of water in China, as seen in the maritime provinces, is thus described :

From these (the main channels), where the tides do not rise sufficiently high for irrigation, water is raised artificially by simple but rude machinery. This consists of a main cog wheel, worked by oxen, which turns a roller at the upper end of the trough ; at the lower end of which, immersed in the canal, there is another roller, and over these an endless series of wooden boxes revolve. The boxes or boards fitting the trough elevate the water and pour it into the fields, over which it is distributed by open drains. The whole machine is readily moved from place to place, and the trough can be arranged at any angle to suit the inclination of the bank.

In other methods of lifting water the ingenuity of the Chinese is strikingly apparent. Of the chain pump there are three adaptations of the same principle. One is operated by animal power, the two others by man power. The first is provided with a mechanism precisely the same, to all intents and purposes, as the horse power suited to the older styles of thrashing machines. This is probably as old as husbandry itself in China. It shows that they understood that power and speed vary inversely, or that power or time is gained according as the moving force is applied near or remote from the axis of a wheel. The chain pump attached consists of a hollow trunk formed of boards, having at each end a short axle provided with cogs, over which an endless chain, having a series of buckets upon it, passes. The trough is placed in an inclined position, with one end in the water to be raised. The upper axle being put in motion by its connection with the power machine (which is placed on the bank of the canal, river, or pond, and operated by a buffalo yoked thereto), causes the endless chain to rotate. The buckets retain the water and raise it to the end of the trough, from whence it flows onto the field. The second description of chain-pump is worked by men, operating upon a description of treadmill with the feet. The upper axle of the endless chain of pumps is extended to a long shaft on either side of the trunk, and provided with short, radiating arms, serving as levers for the action of the feet. A rotary motion is thus communicated to the shaft and the endless chain of buckets. The other description is worked by a crank in the end of the upper axle of the chain pump by hand power.

JAPAN.

In the Island of Lewchew, belonging to Japan, irrigation is so carefully handled as to demand special mention. It is still characteristic of the methods in use. The streams are small and short, brief in their course, and are all appropriated to irrigation. In their management of water the Japanese islanders are always seeking to secure "the retention of water or moisture, and the avoidance of surface washing." In both cases they have succeeded. Dr. Green, U. S. Navy, who accompanied Commodore Perry's expedition to Japan, says :

Wherever a stream is found, whether large or small, also whenever springs issue from the sides of hills (if not excessively steep), the system of grading begins. If the ravine be very narrow, the sides near the bottom are cut down perpendicularly for several feet, and the bottom leveled from side to side, the level becoming wider as the sides recede from each other. It is formed into steps by slight, narrow banks running across, capped with grass. The height of these embankments is always small, rendering the length of the step or plot longer or shorter as the descent of the valley is greater or smaller. A plot of only 6 feet square is not neglected

or despised. Where there is not a ravine, but an open, spreading valley, the sides are not thus cut, but the leveling is effected by running the embankments across it in a curved line corresponding with the ground, the arch being always up the valley. If the stream be large enough to furnish side supplies, open ditches or conduits are carried along the sides, and the water is allowed to descend from plot to plot, the embankments of which are adapted to the surface, being arched outward, or from the side, where an elevation projects into the valley; and inward, or toward the side, where a depression occurs on its face. By this means no dams, as such, are made (liable to be washed away); but gentle descents of a foot or so are made from step to step, without any risk of injury, and requiring only the slightest restraints or banks. These are all covered with grass, and serve as divisions of property and also as pathways. By this simple arrangement great floods may be diffused over level land, and fall from grade to grade so gently as to pass off without detriment to the feeble embankments, and without injury to the soil by washings. This is the grading for irrigated lands. That for rolling lands is not unlike it, but is not brought to such exactness, as a perfect water level is not so much needed. Hillsides are thus cut into terraces, varying in width from a few feet to many yards; and also in length, according to the inclination or shape of the land. The same small margin of grass is found here on the embankments, which are from 1 to several feet in depth ere another terrace is reached. In this way, when the hills are conical and the terraces are arched outward, they look like giant circular steps from base to summit; and where a valley is regular and steep, they are arched inward, and appear as the steps of an immense amphitheater. The terraces are subdivided as the irrigated plots are, or by stones, or slight mounds of earth grassed over as division marks. They are bedded up gently towards the center, and all around the margin there is a slight depression or furrow by which superfluous rain water is carried to some point to be let down to the next level. But before allowing it to escape, it has to pass over a hole or reservoir in the ground, generally partially filled with vines and baulm. Any alluvial soil is thus arrested as sediment to assist in making compost or manure, the water alone escaping. Before escaping finally, however, into a stream or river, it has to traverse a much larger reservoir for the same purpose.

Rice is grown only on irrigated land, which is first saturated, the soil being deeply upturned by the hoe. Where flooded a gang of 2 to 4 men enter each plot of land. Each one of them hoes a row across it, each row about a foot wide, in form like a plow furrow. The plants are then set out, having been first seeded in separate plots. The work is swiftly done, the men moving along, dragging the young plants after them, at intervals of 6 or 8 inches, in the soft earth under water. In front is a sheet of water, behind the laborers is a field of rice, growing in regular rows. Apparently no culture besides digging is required. When dead ripe the rice is harvested. Two crops are grown annually, besides a winter one of sweet potatoes. The uplands are watered only by the rains, skillfully conserved by the system of grading and ditching already described. The cultivation is as minute and careful as in the rice fields.

The agriculture of Japan is carried on in a similar manner as in the island of Lewchew. As to rice, the great staple of Japan, it is sown broadcast in seed beds, which are covered by shallow water, and the seed may be seen lying upon the earth through this water. When drawn the plants are floated by the drains to the place of planting. The ditches used are small, and in general the water or manurial fluids are carried to the plants by laborers. There are about 12,500,000 acres, nearly two-thirds of which are under irrigation, while the population is over 41,000,000. There is no general code of water regulation; as in China, local customs and coöperation control. Peasant proprietors of land is the rule in Japan.

SIAM.

Consul-General Jacob T. Child gives in the State Department Report on Canals and Irrigation (p. 369) the following brief account of irrigation for rice in Siam:

About one-half of the country is under cultivation, and of this portion fully four-

fields is under irrigation. Rice is the staple, consisting of two kinds, *na suan*, or garden rice, which is transplanted, and the second grade, *na muang*, or field rice. It is estimated that about 10,143,800 piculs (1 picul = 133½ pounds) are annually grown in Siam.

Water is supplied to the fields by means of canals, which branch out from the rivers in all directions.

The water is conducted into the fields by small canals and ditches. The fields are divided off into *ris*, containing about one-third of an acre. Around the four sides of each *ri* an embankment is thrown up, about 2 feet in height, with an inlet, to allow the water to each *ri*, in turn, until the whole number of *ris* is full. There are no published works upon irrigation.

This system is governed by laws and customs. There is no duty upon the water, but if the land is Government property there is an annual rental in the form of a tax of 28 cents per *ri*, which includes the use of the water. The large canals are built at the expense of the General Government, but the small canals leading to the fields must be dug by the individual.

The climate is tropical, with a wet and dry season. The average annual rainfall is 67.04 inches.

The system of irrigation has been in use from time immemorial, and is maintained partly by public and partly by private expense.

THE SANDWICH ISLANDS.

The Hawaiian Islands are largely dependent upon irrigation for agricultural security, and the works, therefore, are generally of the most modern description, and are often, too, quite extensive in character. Sugar has increased its yield under irrigation from 2 to 4 tons per acre. There are about 90,000 acres under cane; 7,000 or so under rice; of bananas about 5,000 acres. Half the cane and all the rice fields are irrigated. The water supply is derived from mountain streams, storage reservoirs thereon, springs, and artesian wells. The distribution is generally by means of pipes, which are usually of wrought and cast iron. There are some extensive open ditches from 5 to 40 miles in length. No water code exists; the ownership is by lease, public and private, and the cost (by pumping) is \$3 per month, or \$45 per acre each season. The Kanakas have always used irrigation ditches for the purpose of cultivating "*kala*," from which their chief food, "*poi*," is made. Many of the ancient ditches are still in use. The duty of water is heavy, as rice and sugar require more water than any other crops grown in the world. In Spain, India, Siam, etc., the average duty for cane land is from 45 to 65 acres for one second foot; for rice the duty is one second foot for from 25 to 35 acres. In Hawaii the sugar cane duty is put at one second foot for 41.6 acres, oh the large plantations of the Hawaiian Commercial Company, the duty reaching as high as 65 acres. But the conclusion is reached by engineers of repute—

(1) That while the duty of water is variable with all the varying conditions of soil, climate, rainfall, wind, exposed or sheltered locality, and in some degree with the length of time the land has been irrigated, such variation is generally between the limits of 40 acres as the minimum and 90 acres as the maximum duty of 1 cubic foot per second.

(2) That economy in the application of water below a certain limit, which, for the southerly slopes of this island seems to be about an average of 1 foot in depth per month, can only be exercised at the expense of the yield of sugar.

(3) That a greater duty than 60 acres per cubic foot per second can not be counted on with safety; or, in other words, that 328,500 gallons per acre are needed monthly, or to mature a crop say 15 times that amount, or 4,927,500 gallons, are required. In estimating on the cost of pumping water for irrigation these are convenient figures to remember.

The largest artesian supply is derived from wells bored along the margin of Pearl Harbor. They are almost phenomenal in their volume and extent. They irrigate 20,000 acres of rice, and also a large area in bananas and other products, besides giving power for several large mills.

There are also a number of remarkable springs having considerable flow, 7 of them giving a total of 116 second feet. The measured flow of developed springs is on one of the islands sufficient to irrigate at least 7,000 acres of sugar cane, and probably as high as 10,000 acres. On the island in which Pearl Harbor is situated, there are 100 flowing wells, all of them bored within the past twelve years. Four of these wells would supply with water a city of 165,000 inhabitants. The wells are all confined to a marginal rim around the island back from sea level, at an elevation above it of from 21 to 42 feet. The supply seems unlimited, no diminution being observed.

THE ISLAND OF MADEIRA.

The system of irrigation management practised in the island of Madeira is quite elaborate. The whole area is only about 240 square miles, or 153,600 acres, of which over one-half is irrigated and cultivated. Most of the coastal plane is so utilized. The products are mainly sugar cane, wheat, maize, onions, sweet potatoes, pumpkins, and fruits, of which bananas are a large part. Vegetables are grown successfully at an elevation of 3,000 feet, and most of the cultivation is between 500 and 1,000 feet above sea level. Oranges flourish at 1,500 feet. The water supply is furnished by perennial springs which are filled up with the waters of the rainy season. Water rights and works are termed "levadas," a system which is at least 300 years old. There are no catchment basins or reservoirs, except such as nature has provided and the water itself has plowed and furrowed for its own passage. The "levadas" are open conduits or ditches of open masonry or rock cuts. They show skill and great labor, passing through tunnels, over bridges, or along the precipitous sides of mountains. Some of them are but a few miles while others are from 60 to 70 miles in length. These "levadas" are owned by "committees" of landowners, water being an easement of the soil. The delivery is regulated by custom, upon the horary plan. Some deliver their whole contents in an hour or two; others a quarter at a time just as the proprietors may determine. The quantity issued is considered to be the amount which will run along a furrow at any one time without washing away the soil. To illustrate, the St. Luzia levada has 4,245 hours of water. These rights attach to purchase and inheritance, and were originally acquired through construction of the levada. The managing committee annually sells this water, or rather its use, for an amount sufficient to keep the conduit in repair. Each piece of ground under the levada is entitled to its hours in rotation. When the dry season sets in, a certain period for serving the whole district, called a "gyre," is devised, and this varies from fifteen to sixty days between periods of service. The levadeiro is an official similar to the "water master," "major domo," or the "zanjero" of Utah, New Mexico, Arizona, and Southern California. He is paid by fees, the tariff of which is regulated by the levada committee, who are selected by the proprietors. The prices of a run for the season varies at different parts, rising from \$5 to \$8 in the neighborhood of Funchal. Government levadas have been constructed and turned over to the local bodies. It is reported that they have been allowed to fall into bad order. Water is the most valuable property in Madeira and there is a good deal of litigation over it. United States Consul, T. C. Jones,* says:

One of the principal difficulties attending the management of the levadas was the want of a legal standing as corporate bodies of their committees. A quarrel between

* Canals and Irrigation, Special Consular Reports, 1891; State Department.

two levadas drawing their supply from the same valley occasioned a lawsuit which has lasted now more than forty years.

Within the last few years a law has been passed enabling the committees to incorporate themselves, with power to acquire property and otherwise protect and improve their levadas. They can purchase the land containing their springs, protect the forest and the trees along their lines.

Every farmer of thrift has on his land tanks to store his water, and from these tanks little levadas distribute it when and wherever he wants it.

Water rights are held under title deeds, which specify the intervals at which the supply shall be given and the length of time it shall continue.

Water is always of ready sale. If a crop fails from any cause, the water for that land is sold to a more fortunate neighbor, though sometimes at a very reduced rate.

Under any system it is hard for the poor. Their supply is scant, and they must receive it when their time comes, seasonable or unseasonable, day or night, and without tanks they can not care for or properly distribute it.

The rainfall along the coast belt is about 28 inches per annum. An important work is now in progress by which the water collected in a gorge, considered heretofore as inaccessible, will be delivered by means of a large levada and conveyed to a fruitful valley, which has suffered from loss of its old supply. The source is 4,700 feet above the sea. After entering the valley the water will flow down a series of cascades with a fall of more than 300 feet.

A constant flow of a pint of water is sufficient to irrigate 5 acres of ground; that is, the water must flow into a reservoir and be used from that as required.

The regulation for the government levadas are interesting, especially those which related to the duty of the "care-takers."

MADAGASCAR.

Irrigation by flooding for rice culture is the only mode practiced in Madagascar. The water is applied direct through shallow channels constructed of grass and mud, or through other material that may be at hand. Water is used without restriction or cost other than the labor required in its direction. It seems to be generally accepted as community property.

EXTENT AND IMPORTANCE OF ANCIENT WATER SUPPLY AND IRRIGATION WORKS.

(The following interesting statements are from a paper read by Civil Engineer Frederick S. Gipps, before the Royal Society of New South Wales, in December, 1887.)

The numerous remains of huge tanks, dams, canals, aqueducts, pipes, and pumps in Egypt, Assyria, Mesopotamia, India, Ceylon, Phœnicia, and Italy, proved that the ancients had a far more perfect knowledge of hydraulic science than most people are inclined to credit them with. To this experience it seems to me may be contributed the construction of many of those monuments and temples immortalized by their gigantic and imperishable ruins, the astonishment and admiration of the ancient historian as well as of the modern traveler. I am partially warranted in this assumption by the fact that the Egyptians ran canals through their quarries, by which, when filled by the inundations of the Nile, they transported on rafts proportionate to their weight huge masses of stone for columns or obelisks to the positions at which they were required, the whole country being intersected with numerous canals. Without doubt the Egyptians, Chinese, and East Indians have from time immemorial raised water both for irrigation and turning mills, and it is therefore probable that, understanding its property as a motive power, they applied it in the construction of some of their magnificent temples. . . . After a careful perusal of the records of history, it appears to me impossible to assert with confidence what particular nation originated the construction of reservoirs, canals, and water machinery.

The priests of Egypt believed that all things were composed of water, whilst Thales, the Milesian, taught that all things originated from water. The first artificial lake of which there is reliable record was Lake Maeris. The historians Herodotus, Diodorus, and Pliny have described it, on the testimony of the inhabitants of the country, as one of the noblest works of the time, from its enormous dimensions and its capacity for irrigation for the benefit of mankind. According to them it was about 3,600 stadia or 413 miles in circumference, and 300 feet deep. Modern travelers have considerably reduced the circumference and depth of this lake, making it measure somewhat less than 50 miles, but even with this curtailment it must have been a magnificent engineering work, worthy the admiration of all the ages. It was constructed, some historians say, by King Maeris, others by King Amenemhet III, in the twelfth dynasty, 2084 B. C. Its principal object was to regulate the inundations of the Nile River, with which it communicated by a canal about 12 miles long and 50 feet broad. When the inundation rose over 24 feet, and was likely to be disastrous to the crops, the sluices were opened and the flood was relieved, owing to their drainage through the canal into the lake; when the Nile rose only 12 feet and drought threatened the crops, the dearth was neutralized by the storage waters of the lake. As the Egyptians were so dependent on the inundation of the Nile for their welfare, even for their means of liveli-

hood, they made careful observations by fixed measures of the height of its inundation, extending over a long series of years, from which it was ascertained that if the flood rose only 16 feet a famine was threatened, or if over 24 feet a disastrous flood might be anticipated.

Sesostris, one of the most illustrious kings of antiquity, who reigned in Egypt 1491 B. C., had a great number of canals cut for the purpose of trade and irrigation, and is said to have designed the first canal which established communication between the Mediterranean and the Red Sea. This work was continued by Darius, who abandoned it because he thought the Red Sea was higher than Egypt, and would therefore deluge the whole country, and it was finally completed under the Ptolemies. Irrigation canals are so numerous in Egypt and irrigation is conducted on such an extensive scale that it is calculated only one-tenth of the water of the Nile which enters Egypt passes through the Mediterranean Sea.

The Assyrians were equally renowned with the Egyptians from the most remote periods of history for their skill and ingenuity in the construction of hydraulic works. Through the foresight, enterprise, and energy of their rulers they converted the sterile country in the valleys of the Euphrates and Tigris into a fertility which was the theme of wonder and admiration of the ancient historians. The country below Hit, on the Euphrates, and Samarra, on the Tigris, was at one time intersected with numerous canals; one of the most ancient and important of which, called the Nahr Malikah, connecting the Euphrates with the Tigris, is attributed by tradition to Nimrod, King of Babel, 2204 B. C., whilst other historians assert that Nebuchadnezzar constructed it. It seems that during June, July, and August the volume of the river Euphrates increased so rapidly that it threatened to overflow its banks and cause considerable damage to Babylon and its neighborhood, and it was therefore considered necessary to raise high banks on both sides of the river, built of brick cemented with bitumen, to protect the city. To facilitate this purpose a big lake was dug out 42 miles in circumference and 35 feet deep, into which the whole river was turned by an artificial canal. When the embankments were completed the river was restored to its original channel, whilst the lake served as a storage reservoir for collecting flood waters and distributing them for irrigation. With the destruction of Babylon the glory of the empire departed, the canals were neglected, and the country, described by Herodotus as being prolific before all other lands in its production of corn, wheat, and barley, has become so dry and barren that it can not be cultivated. The principal canals supplied by the Euphrates were the Nahr Malikah or Fluvius Reginis, the Nah-raga, the Nahr Sares, the Kutha, and Pallacopus. The Tigris supplied the Nahrawan and Dyiel, besides several small canals. The whilom great importance of the Nahrawan, both for commerce and agriculture, and its great antiquity, are testified to by the ruins of numerous towns and cities on both of its banks. It started on the right bank of the Tigris, where the river debouches from the Hamrine Hills, and flowed at a distance of 6 or 7 miles from the river toward Samarra, where it was joined by a second conduit. About 10 miles farther on it received a third feeder from the river, and then continuing its course it approached Bagdad. A few miles lower down it flowed into the Dyalah or Shirwan River, which was raised by a large band or weir to a sufficient height to allow of its continuance. It then proceeded through Kuzistan, absorbing all the streams from the Sour and Buckharee mountains, and finally flowed into the Kerkha River. It was over 400 miles long and of immense dimensions, its width vary-

ing from 250 to 400 feet, and by numerous branches on both sides it irrigated a very extensive area of country, whilst at the same time it was available for navigation. Few, if any, hydraulic schemes of modern days equal in boldness of conception this stupendous achievement of a generation of four thousand years ago. The present irrigation canals deriving their supply from the Tigris, known as the Boogharib, Massoode, Desodee, Rithwammibi, and Mahmondee are very insignificant in comparison with the Nahrawan.

The remains of reservoirs in the neighborhood of Hebron, which the Jews are supposed to have constructed in the days of Solomon, for the supply of Jerusalem, show that their designers were equally alive with most engineers of the present age to the great importance of an ample and constant supply of pure water. A large portion of the supply conduit consisted of earthen pipes cased with stone hewn out to fit them, which again were covered with rubble in cement; thus the coolness and purity of the water was perfectly preserved. The Phœnicians in the zenith of their power were celebrated for their canals, both for the supply of Carthage with drinking water and for the purposes of irrigation. Agathocles, the daring, but unfortunate, Syracusan general, who thought by his invasion of Africa to force Carthaginians to raise the siege of Syracuse, left this record of his disastrous invasion, that "the African shore was covered with gardens and large plantations, everywhere abounding in canals, by means of which they were plentifully watered. The lands were planted with vines, palms, and many other fruit trees, and the meadows were filled with flocks and herds." When the Romans invaded Carthaginian dominions fifty years later, their historian, Polybius, drew a somewhat similar picture of their fertility and high state of cultivation. But, undoubtedly, the conduit which supplied Carthage with drinking water was their most notable achievement in water-works. It derived its supply from a spring about 60 miles distant from the city, and its course cut through mountains by tunnels and crossed valleys by lofty and massive aqueducts, in one instance 125 feet high. It was 4 feet wide at the base and 6 feet high, closing at the top in the shape of a pyramid, and was sufficiently high for a man to walk in with ease. It was covered throughout, for sanitary reasons, and was constructed most substantially of masonry lined internally with cement, which has preserved it from the attacks of time so well that even now a large portion of it is used for the supply of Tunis, which derives its water from the same source.

The Grecians, judging from the ruins of large aqueducts scattered throughout their country, appear from a very remote period to have paid the greatest attention to hydraulic science. Herodotus describes an ancient conduit for supplying Samos, which had a channel 3 feet wide and which pierced a hill with a tunnel nearly a mile long. Another masonry aqueduct near Patara crossed a ravine 200 feet wide and 250 feet deep. It was constructed of masonry in cement. The stone blocks three feet cube had a bore through the center of 13 inches in diameter, and joints were formed similar to a spigot and faucet joint by the annular end of a block fitting into a recess of the opposite end of another block. The joints were secured by cement and also by iron clamps run with lead. This aqueduct had a considerable depression in the center, and appears to have been one of the first attempts to run water in an inverted siphon, proving that the ancient Greeks had a thorough knowledge of the principle that water will rise to the level of its source.

The Romans having vanquished all rival empires hastened to take

advantage of the knowledge they had acquired in their conquests, and in the construction of numerous grand and beautiful public works became not only renowned for their prowess in arms, but also for their high appreciation of the arts and sciences. They appear to have been especially scrupulous as to the purity of their drinking water and as to the cleanliness of their person. To insure the first, they constructed the Aqua Martia, which was covered throughout, and to encourage the last they built numerous baths.

In the reign of the Emperor Nero, Rome was supplied by no fewer than nine large conduits, having an aggregate length of 255 miles, which delivered over 173,000,000 gallons daily. Afterwards the supply was increased to 312,500,000 gallons daily, equal to a rate of 325 gallons to each inhabitant. The Aqua Martia conduit, which alone supplied the drinking water, was 16 feet in diameter and 40 miles long. One of the principal aqueducts it crossed is remarkable for the grandeur of its dimensions, and for the skillfulness of its construction. It had to sustain three large conduits, the Julia, Sepula, and the Aqua Martia, and the greatest precaution was exercised to prevent the two first from draining into the lower one, and thus deteriorating its waters. Strabo, in alluding to the skill of the Romans in the application of hydraulics, remarks that not only were there subterranean conduits at Rome, but that all the houses had siphons or water pipes which probably could be used to extinguish accidental fires. * * * They drained the Pontine marshes, and so improved the river system that, according to their historians, there was no river in Italy that was not made useful for the purpose of commerce and the transport of troops and provisions. Not content with thus developing the resources of their own country, they studied, wherever victory led the way, to improve the condition of the vanquished by similar public works. They constructed a series of large reservoirs along the range of the hills nearly bordering on the Black Sea, from which they supplied large covered cisterns in Constantinople with a pure and constant stream of water. In France they constructed conduits to supply Lyons, Frejus, Sens, Metz, and Nismes. The first, owing to the boldness of its conception and the skillfulness of its construction, and because it is one of the first known instances of the use of metal pipes subjected to any great pressure, is worthy of more than passing notice. It was designed especially for the purpose of supplying the palace of Claudius, situated in the highest part of the town. * * * The Nismes conduit, constructed in time of Augustus, B. C. 19, which delivered 14,000,000 gallons daily, is celebrated for a magnificent aqueduct called the Pont du Gard. Humble describes it as one of the grandest monuments the Romans have left in France or any other country. * * * Again, in Spain and Portugal they supplied the towns of Segovia, Seville, Evora, and Lisbon by means of conduits of considerable length, which crossed deep valleys on aqueducts of great magnitude, which, however, present no very remarkable features worthy of further comment.

China is equally celebrated with Egypt for the great antiquity of its numerous canals. The Great or Imperial Canal is one of the most stupendous works of ancient or modern times. It is 650 miles long and connects the Hoang-Ho and Yang-tse-Kiang rivers. Its depth is seldom more than 5 or 6 feet, whilst in dry seasons it is considerably less. To regulate its fall it is provided with a number of solid wooden sluices, over which vessels are hauled by machinery and let down on the other side. * * * Its average velocity is $2\frac{1}{2}$ miles per hour, and in its course it crosses several large lakes on the top of enormous dykes. It

is available both for navigation and irrigation, and, together with its numerous branches, irrigates an immense area of country, thus affording millions the means of livelihood and support.

Again, in the Malay Archipelago irrigation is carried out to such perfection as to excite the astonishment of the distinguished naturalist, Mr. Wallace, who thus described it:

It was here that I first obtained an adequate idea of one of the most wonderful systems of cultivation in the world, equaling all that is related of Chinese industry, and, as far as I know, surpassing in the labor bestowed on it any tract of equal extent in the most civilized countries of Europe. I rode through this strange garden utterly amazed and hardly able to realize the fact that in this remote and little known island, Lombook, from which all Europeans (except a few traders at the port) are jealously excluded, many hundreds square miles of irregularly inundating country have been so skillfully terraced and leveled and so permeated by artificial channels that every portion of it can be irrigated and dried at pleasure.

Many ancient native writers testify to the high estimation entertained by the inhabitants of India for water supply for irrigation purposes. The "Vishnood" declares that "no satisfaction is felt without water in the three worlds, Heaven, Hell, and Earth; therefore a wise and learned man should cause reservoirs, tanks, and wells to be made. The Yama-porans teaches that "a person in whose pond or tank there is a constant supply of water obtains perpetual felicity without doubt; and the Bhewish-Yotara-poonau exclaims: "O thou, son of Kooni, get large supplies of water made at the sacrifice of your whole property, for the man at whose reservoir the cow slakes her thirst becomes the preserver of his family."

Immense tanks or reservoirs and irrigating canals appear to have been constructed in India many centuries anterior to the advent of Christ, and some of them are probably equally as ancient as the Egyptian canals. The Cummin tank in Madras has an embankment of 102 feet high, and of considerable length. The Naggar-Sulikerrai has an embankment 84 feet high and 603 feet wide at the base, which incloses an area of 40 square miles. In Bombay the Lachura tank is about 3 miles in circumference. In Ceylon the Mincheri tank forms a beautiful lake of over 20 miles in circumference. The Kalucarri tank forms a lake 60 miles in circumference by an embankment 15 miles long and 300 feet wide at base. Many of these immense embankments consist only of well trodden clay resting on the surface of the ground, and are constructed without the application of any particular engineering skill, no puddle walls having been used to render them more water-tight.

**WATERWORKS, EAST OF "ARID REGION," HAVING THEIR
SUPPLY FROM ARTESIAN AND UNDERFLOW SOURCES.**

**ABSTRACT FROM "MANUAL OF AMERICAN WATERWORKS, 1889-'90."
("ENGINEERING NEWS.")**

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Waterworks (east of "arid region") having their supply from artesian and underflow sources.

[The problems involved in a water supply from phreatic or sub-surface sources are of a character on which all desirable data should be presented. As a part of the study of its importance and to aid in understanding what is signified under the conception of water conservation and management, these carefully arranged tables are furnished.]

ALABAMA.

City, town, or village.	Supply (wells, springs, etc.).	Consumption.	Capacity of reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.
Anniston	Artesian well and springs.....	Gallons. 450,000	Gallons. 10,375,000	Pumping to reservoir and standpipe.	Estimated daily capacity 4,000,000 gallons.
Bessemer	Spring-fed streams	1,300,000	8,000,000	Pumping to standpipe and gravity.	Daily flow 2,000,000 gallons.
Fort Payne	Springs (?)	a	200,000	Pumping to standpipe.....	In 1898, capacity of 6 wells was 5,000,000 gallons daily.
Huntsville	Spring	500,000	200,000	Pumping to reservoir.....	
Jacksonville	Springs	500,000	1,000,000	Gravity to and from reservoir.....	
Montgomery	Artesian wells	1,350,000	3,917,000	Gravity and pumping.....	
Selma	do	2,000,000	100,000	Pumping to standpipe and direct.....	
Spring Garden	Springs	1,000	60,000	Pumping to reservoir.....	
Talladega	Spring	40,000	138,000	Pumping to standpipe.....	
[Proposed works.—Troy: Well; franchise granted. Uniontown: Has artesian wells.]					

ARKANSAS.

Alexander	Springs	a	8,000	Gravity	Daily capacity of springs, 875,330 gallons. 10 wells to be added. Two wells contracted for. Month.
Brinkley	Deep well	a	75,000	Pumping to tank	
Hope	Artesian well	a	60,000	do	
Hot Springs	Springs and bayou	a	1,000,000	Pumping to reservoir.....	
Line Bluff	Cook wells (near river)	a	85,000	Pumping to standpipe and direct.....	
Rogers	Spring	a		Pumping to tank	
Texasiana	10 flowing Wagner wells	1,000,000	3,000,000	Pumping	
[Works projected.—Hatesville: Has spring with capacity 400,000,000 gallons. Beebe: Artesian well being sunk. Helena: Two wells contracted for. Montello: Works in progress; Stuttgart: Driven wells proposed.]					

a Data not given. The same in all other items indicated by letter a.

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.

CONNECTICUT.

City, town, or village.	Supply (wells, springs, etc.).	Consumption.	Capacity of reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.
Asonia	Spring	Gallons.	Gallons.	Gravity from reservoir.	Has other works.
Birmingham	Spring and surface water	a	a	do	Two reservoirs, 9 and 27 acres.
Canaan	Spring and surface water	a	a	do	Dam 150 feet long, 12 feet high.
State Industrial School	Spring-fed brook	a	5,000,000	do	
Danielsonville	Spring	a	16,750,000	do	
Durham	Spring	a	a	Gravity from reservoir.	Reservoir, capacity 14 acres.
Kent	Spring and surface water	a	a	Gravity from reservoir.	Proposed new reservoir, capacity 1,000,000,000 gallons.
Newington	Mountain springs	a	a	Gravity from reservoir.	Lake capacity 30,000,000 gallons.
Norwich	Spring-fed lake	1,400,000	350,000,000	Gravity from reservoir.	
Stamford	Spring-fed lake	1,000,000	8,500,000	Gravity to and from reservoir.	
Thomaston	do	a	65,000,000	Gravity from reservoir.	
Thompsonville	Spring	1,400,000	185,000,000	Pumping to tank	
Waterbury	Spring and surface water	a	a	Gravity from reservoir.	
Windsor	Spring	15,000	8,000,000	Gravity	

DELAWARE.

Dover	Wells (2)	59,102		Pumping direct.	
Newark	Well	50,000	184,000	Pumping to standpipe and direct.	
Newcastle	Spring-fed creek	450,000	1,250,000	Pumping to reservoir.	

FLORIDA.

Fernandina	Artesian well	20,000	113,000	Pumping to tank.	
Jacksonville	Artesian well (3)	878,207		Pumping direct.	Combined flow of wells 4,700,000 gallons daily.
Melbourne	Artesian well	a	a	Gravity	
Ocala	do	50,000	130,000	Pumping to tank	
Palm Bay	Spring-fed stream	675,000	183,000	Pumping to standpipe	
St. Augustine	Artesian wells	1,000,000	400,000	do	
Sanford	Spring-fed lake	135,000	500,000	Gravity and pumping.	
Seville	do	a	50,000	Pumping to tanks	
Tampa	Artesian well and spring	130,000	111,000	Pumping to tank	Spring; daily capacity 1,600,000 gallons.
[Works projected at other points.—Supply from wells or springs.]					

GEORGIA.

Americus	Springs	100,000	Pumping to tank	Has an artesian well that supplies the
Adahns	Springs (6)	175,000	Pumping to standpipe	existing hydrant. Main supply.
Atlanta	See "Remarks"	23,300,000		
Bainbridge	Artesian wells	15,000	Pumping to tank	
Brunswick	do	400,000	do	
Cartersville	Springs (on river bank)	a	Pumping from reservoir to stand-	
Dalton	Springs	75,000	pipe	
Fort Gaines	Artesian well	31,000	Pumping to tank	
Macon	Springs	12,000	Pumping to tank and reservoir	
Rising Fawn	Springs	1,600,000	Pumping to reservoir	
Rome	Wells	a	Pumping to standpipe	
Savannah	Artesian wells (9), and river, if	330,000	Pumping direct	Works not completed.
	necessary	6,000,000		
Thomasville	Artesian wells (2)	80,000	Pumping to standpipe	Reservoir data refers to river supply.
Tybee	Artesian wells	12,000	Pumping to tank	
	Supply from wells or springs	a	Pumping to tank	
	(Protected wells)			
ville: Springs. Trenton: Springs.	Washington: Springs. Cordele: Has artesian well. Fort Valley: Contract let; supply artesian well. Le Grange: Wells. Milledge-			
	Waycross: Bonds voted. Waynesboro: Has artesian well; daily yield 100,000 gallons.]			

ILLINOIS.

Aledo	Artesian well	a	Pumping to tank	Report for 1887-'88.
Barry	do	46,000	do	
Bloomington	Type and surface wells	47,000	Pumping to standpipe and direct	
Blue Island	Well	75,000	Pumping to tank	
Blue Mound	do	60,000	Pumping to tank and direct	
Buckley	do	25,000	do	
Cabery	Artesian well	a	do	
Canton	Artesian and surface wells	15,000	Pumping to standpipe and direct	
Carthage	Well	35,000	Pumping to reservoir and direct	
Clinton	Artesian well	131,770	Pumping direct	
De Kalb	Artesian well	60,000	Pumping to tank	
Duquoin	Springs and river	a	Pumping to reservoir and direct	
El Paso	Artesian well	100,000	Pumping to reservoir	
	Well (combined surface and	36,100	Pumping to tank and direct	
	river)		do	
Eureka	Artesian wells and river (18	28,100	do	
Freeport	wells)	115,500	do	
Fulton	Well	100,000	Pumping to reservoir and direct	

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.

ILLINOIS—Continued.

City, town, or village.	Supply (wells, springs etc.).	Consumption.	Capacity of tank or standpipes.	Mode of service (pumping or gravity).	Remarks.
Galena.....	Artesian well.....	Gallons.	Gallons.	Pumping to standpipe and direct.	No report since 1884. Daily yield of one well in 1887, 275,000 gallons.
Galesburg.....	Wells.....	30,000	125,350	Pumping to reservoir and direct.	
Geneseo.....	Artesian wells (2).....	30,000	50,000	Pumping from reservoir.....	
Greenville.....	Well.....	100,000	30,000	Pumping direct.....	Report for 1887-'88.
Havana.....	Gravel beds under grounds.....	a	50,000	Pumping direct and to standpipe.	
Hoopeston.....	Well.....	a	30,000	Pumping to tank and direct.	
Jerseyville.....	Deep well and reservoir.....	a	30,000	Pumping to tank.....	
Joliet.....	Artesian well.....	1,700,000	41,900	do.....	
Kewanee.....	Artesian wells and pond.....	a	a	Pumping to standpipe and direct.	
Lemont.....	Well.....	80,000	100,000	Pumping to reservoir and direct.	
Lewiston.....	Driven well.....	a	55,000	Pumping to reservoir.....	
Lincoln.....	Wells.....	223,856	150,000	Pumping to standpipe.....	
Lockport.....	Artesian well.....	a	500,000	do.....	
Madison.....	do.....	a	170,000	Pumping to reservoir.....	
Menom.....	Well.....	a	57,000	Pumping to tank.....	
Monmouth.....	Artesian well.....	58,000	300,000	Pumping to reservoir.....	
Morgan Park.....	do.....	30,000	100,000	Pumping to tank.....	
Morrisson.....	Spring.....	50,000	a	do.....	
Mount Pulaski.....	Well.....	150,000	50,000	Pumping to tank and direct.	
Mount Carroll.....	do.....	32,800	a	do.....	
North Park.....	Artesian well.....	a	a	Pumping from reservoir to tank.	
Ottawa.....	Wells.....	100,000	a	Pumping to standpipe.	
Peoria.....	Spring.....	180,000	a	Gravity.....	
Petersburg.....	Wells.....	4,000,000	889,000	Pumping to standpipes (2).....	
Pittsfield.....	Tub wells (4).....	80,000	185,000	Pumping to tank.....	
Riverside.....	Artesian well.....	a	30,750	do.....	
Rockelle.....	do.....	a	42,000	do.....	
Rockford.....	Springs.....	54,000	a	Pumping direct.....	
Sandwich.....	Artesian wells (5).....	1,033,942	a	Pumping to standpipe and direct.	
Savanna.....	Well.....	28,800	84,600	Pumping to reservoir.....	
Somonauk.....	Well (combined surface and driven).....	100,000	750,000	Pumping to tank.....	
	Well.....	a	90,000	Pumping to tank.....	

Sterling and Rock Falls ..	Artesian wells and river ..	300,000	Pumping to standpipe ..	Artesian well for fires
Streator	Tube and artesian wells and creek ..	500,000	do	
Sullivan	Well	a	Pumping to tank	
Sycamore	Surface and tube wells	35,000	Pumping to standpipe and direct ..	
Taylorville	Artesian well	a	Pumping to tank and direct ..	
Washington	Driven wells	a	Gravily	Well for fires
Waukegan	Spring	a	Pumping to standpipe ..	
Yorkville	Spring	1,000	do	
[Projected works at other points; some already having artesian supply.]				

INDIANA.

Attica	Springs	9,000	Pumping to reservoir	
Bluffton	Wells (near river)	200,000	Pumping direct	
Crawfordsville	Springs (daily flow 4,000,000 gallons) ..	a	Pumping to reservoir, standpipe, and direct ..	
Elkhart	Well	450,000	Pumping to tank and direct ..	Daily yield 600,000 gallons.
Goshen	Artesian wells (6)	500,000	do	
Granger	Tube wells	a	Pumping direct ..	
Hammond	Well	200,000	Pumping to standpipe ..	
Kendallville	do	250,000	do	
Kokomo	Artesian wells and creek ..	a	Pumping direct ..	
Lagomer	Well	50,000	Pumping direct and to tank ..	
Marion	do	130,000	Pumping direct and to tank ..	In 1881.
Michigan City	Springs	800,000	Pumping direct ..	
Muncie	Artesian wells	500,000	Pumping direct and to tank ..	
New Castle	Well	20,000	Pumping ..	
Plymouth	Driven wells (5)	12,000	Gravily and pumping ..	
Ellettsville	Springs	1,000,000	Pumping to reservoir and direct ..	In 1887.
Salmon	Well	130,000	do	
Shelbyville	Well	2,500	Pumping to standpipe ..	
South Bend	Artesian wells (11)	1,750,000	Pumping from reservoir to standpipe ..	Daily flow of well, estimated, 2,600,000 gallons.
Wabash	Driven well, springs, and creek ..	250,000	do	
[Projected works at other points; supply to be artesian.]				

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.

IOWA.

City, town, or village.	Supply (springs, wells, etc.).	Consumption.	Capacity of reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.
Atlantic	"Cook wells"	Gallons.	Gallons.		
Autumn	Well	250,000	104,000	Pumping direct	
Barnes	Artesian wells	50,000	22,000	Pumping to tank	
Cedar Falls	Springs	50,000	100,000	Pumping to tank and direct	
Cedar Rapids	Artesian wells and river	1,000,000		Pumping to tank	
Charles City	Spring	a		Pumping direct	3 1/2-inch wells for domestic, and river for fire, purposes.
Cherokee	Artesian wells	a	182,000	do	
Clarinda	Driven wells	100,000		Pumping to standpipe	
Clinton	Artesian wells (3)	1,000,000	325,000	Pumping direct	Wells 5 1/2-inch diameter, 1,100 feet deep.
Colfax	Driven wells (3)	30,000	70,000	Pumping to tank and direct	Well 20 feet diameter and 30 feet deep; in gravel.
Decorah	Well (surface)	32,000	400,000	Pumping to reservoir	
Denison	do	a	100,000	Pumping to tank	A abandoned mines drainage tunnel, 100 to 200 feet below surface.
Dubuque	Tunnel	16,324	1,750,000	Gravity	6 inch driven well, 100 feet deep; in bottom of surface well 40 feet deep.
Eldora	Combined driven and surface well	a	100,000	Pumping to tank	
Gladbrook	Artesian well	a	30,000	do	
Hawarden	Driven wells	800	40,000	do	
Holstein	Well	a	50,000	do	
Ida Grove	Driven wells (25)	a	100,000	do	
Iowa City	Driven wells and river	18,000		Pumping direct	
Jackson	Wells (160 feet deep)	200,000		do	
Laurens	Driving wells (2)	350,000		Pumping direct	
Le Mars	Driven wells	50,000		Gravity	
Logan	Wells (2)	150,000	250,000	Pumping direct (from reservoir for fires)	
Marion	Springs (2)	a	90,000	Pumping to reservoir	
Mason City	Springs (and river for fire)	300,000	614,700	Pumping from reservoir to standpipe	Daily capacity of springs, 2,025,000 gallons.
Maquoket	Driven wells (10)	a	150,000	Pumping direct	
Monticello	Artesian well	185,000	500,000	Pumping to reservoir	
Neola	Well	a	50,000	do	
Newton	do	a	60,000	Pumping to tank and direct	
Newton	Artesian well	a	97,000	Pumping to tank	
Odebolt	Driven wells	a	100,000	Pumping to reservoir	
Red Oak	Filter gallery (and river for fire)	5,000	58,000	Pumping to tank	
Reinbeck	Well	a	400,000	Pumping direct	
			50,000	Pumping to tank	Report prior to 1899.

Rock Rapids.....	"Drive Points" (50).....	a	37,000	Pumping to standpipe.....	Daily yield, 2,000,000 gallons.
Sioux City.....	Driven wells (104 2-inch).....	a	1,500,000	Pumping to reservoir.....	In 1887.
Sioux Rapids.....	Well.....	a	84,000	Pumping to tank.....	
Sioux Center.....	Wells (2).....	a	1,500	do.....	
Tipton.....	Artesian well.....	a	47,000	Pumping to standpipe.....	
Villisca.....	Wells supplied by springs.....	a	47,000	Pumping to tank.....	
Winton.....	Artesian well and river.....	a	88,000	Pumping to tank and direct.....	
Webster City.....	do.....	a	75,000	Gravity.....	
Wells City.....	do.....	a			Daily yield in 1889, 170,000 gallons.

[Note.—Works are proposed or projected at several other places in State, with artesian wells, springs, etc., for the supply.]

KANSAS (EAST OF THE 100TH MERIDIAN).

Anthony.....	Driven wells (18).....	a	100,000	Pumping to standpipe.....	Daily yield of wells 500,000 gallons.
Argentine.....	Wagner wells (6).....	a	500,000	Pumping to tank.....	Supply in 1889, 500,000 gallons daily.
Blue Rapids.....	Wells.....	a	200,000	Pumping to reservoir.....	
Columbus.....	Artesian well.....	a	75,000	Pumping to standpipe and direct.....	
Council Grove.....	Well.....	a	25,000	do.....	
Girard.....	Artesian well.....	a	60,000	Pumping to tank.....	
Greenleaf.....	Wagner wells (8 6-inch).....	a	80,000	Pumping to standpipe.....	
Horton.....	Wells (surface).....	a	80,000	do.....	
Junction City.....	Driven wells (30 near river).....	a	100,000	Pumping to reservoir.....	
Marysville.....	Wells.....	a	60,000	Pumping to tank and direct.....	
Pittsburg.....	Artesian well.....	a	67,000	Pumping to tank.....	
Valley Falls.....	Wells.....	a	70,000	Pumping to tank and direct.....	
Weir.....	Artesian well.....	a	50,000	Pumping to tank and direct.....	

KENTUCKY.

Georgetown.....	Spring.....	a		Pumping direct.....	Daily flow 5,500 gallons.
Glasgow.....	do.....	a	100,000	Pumping to reservoir.....	Shelbyville: Artesian, or surface well.
Mayfield.....	Deep wells.....	a	160,000	Pumping to tank.....	
Middleboro.....	Artesian wells.....	a		do.....	
Pleasant Hill.....	Spring.....	a	4,482	Pumping to tank.....	
[Proposed or projected works (supply from wells or springs)—Princeton: Artesian well. Richmond: Wells (or lake). Standford: Large springs.]		a	4,000		

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.

LOUISIANA.

City, town, or village.	Supply (wells, springs, etc.).	Consumption.	Capacity of reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.
		Gallons.	Gallons.		
Alexandria.....	Artesian wells.....				Two wells contracted for to supply 100,000 gallons daily. 1887.

MAINE.

Brunswick.....	Springs and river.....	300,000	7,025,000	Pumping to standpipe.....	
Diamond Island.....	Springs.....	5,000	73,000	do.....	
Hallowell.....	do.....	b	50,000	Gravity.....	
Old Orchard.....	Springs.....	60,000	116,000	Pumping to standpipe.....	
Rockland.....	Spring-fed streams.....	b	300,000	Gravity (pumping direct for fires).....	
Camden, and Thomaston.....	Spring-fed lake.....	b	2,500,000	Gravity to reservoir.....	
Sanford.....	Springs.....	7,000	32,000	Pumping to tank and direct.....	
Shawhegan.....	do.....	b	275,000	Pumping to standpipe.....	
South Norridgewock.....	Spring.....	b	15,000	Pumping to tank.....	
Springvale.....	Springs.....	b	30,000	do.....	
York Beach.....	Artesian wells.....	b	25,000	do.....	City has other works; supply, surface water.

MARYLAND.

Annapolis.....	Springs and surface water.....	b	8,250,000	Pumping to reservoir.....	
Catonville.....	Artesian well and stream.....	150,000	650,000	Pumping to tanks.....	
Chestertown.....	Springs.....	40,000	1,000,000	Pumping to reservoir.....	
Easton.....	Artesian wells.....	50,000	84,000	Pumping to standpipe.....	
Frederick.....	Artesian wells, springs, and mountain stream.....	b	1,500,000	Gravity.....	
Frostburg.....	Artesian wells (4) and springs.....	35,000	1,000,000	do.....	
Hagerstown.....	Artesian wells and spring-fed.....	500,000	20,000,000	do.....	
Mechanicstown.....	Mountain springs.....	50,000	300,000	do.....	

MASSACHUSETTS.

	12 6-inch wells and river (for fire). Springs.	27,000	84,000	Pumping to standpipe and direct.. Pumping from receiving to dis- tributing reservoir. do
Salsbury				
Union Bridge		50,000	480,000	
Westminster	Springs (3)	12,000	1,500,000	
[Projected works.—Cambridge: Probable supply, well.]				
MASSACHUSETTS.				
Acswam	Springs	a	a	Gravity
Amesbury	Driven wells	a	2,300,000	Pumping to reservoir
Amherst	Springs and brook	a	2,800,000	Gravity
Ashburnham	Springs	a	1,000,000	Gravity from impounding reser- voir
Attleboro	Well and river		215,000	Pumping to tank and direct
Avon	Spring-fed well	a	500,000	Pumping to standpipe and direct
Ayer	Well		100,000	Pumping to reservoir
Barnstable	Wells (near river)		270,000	Pumping to standpipe
Brookfield	Springs	a		Gravity
Burlington	Well (filter)		467,000	Pumping to standpipe
Canton	Spring-fed brook	a	900,000	Gravity
Cheshire	Wells and spring-fed brook	a	8,530,000	Gravity and pumping to tank
Chillicothe	River and springs	a		Pumping to reservoir
Chillicothe Falls	Springs and surface water	a	60,000,000	Gravity from reservoir
Clinton	Driven wells (65 2-inch wells)	a	1,500,000	Pumping to reservoir
Cohasset	Spring-fed lake (for fires only)	a		Pumping direct
Cottage City				
Deatham	Well (3)	180,000	540,000	Pumping to standpipe
Easthampton	Springs and pond		000,000	Pumping direct—pond, gravity, springs
Franklin	Wells	60,000	423,000	Pumping to tank
Grafton and North Grafton	Artesian well and surface well	125,000	110,000	Pumping to standpipe
Haverhill	Springs and ponds		210,000	Pumping to standpipe and gravity
Hinsdale	Springs and brooks	a	40,000,000	Gravity from reservoir
Holyoke	Spring-fed ponds	a	70,000,000	Gravity
Hopkinton	Artesian wells (4)		500,000	Pumping to tank
Hyde Park	Well and river		250,000	Pumping to reservoir
Keene	Well and river		1,385,000	Pumping direct
Lancaster	Springs and well		605,000	Gravity
Lenox	Springs and river		1,000,000	Gravity and pumping
Malden	Driven wells and pond		1,000,000	Pumping to standpipe and tank
Mansfield	Springs	130,000	945,000	Pumping to standpipe and direct..

a Projected

b Data not given.

Pumping machinery, capacity 500,000 gallons; new works—supply springs (by gravity), in progress.

Springs furnish one-half of supply.

Capacity of another reservoir not given.

Well yields 70,000 gallons daily.

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.
 MASSACHUSETTS—Continued.

City, town, or village.	Supply (springs, wells, etc.).	Consumption.	Capacity of reservoir, tank or standpipe.	Mode of service (pumping or gravity).	Remarks.
Marblehead.....	Driven wells.....	Gallons.	Gallons.	Pumping to standpipe.....	Wells for domestic use. River for fires.
Middleboro.....	Well.....	120,000	a	Pumping to standpipe and direct.....	
Milford and Hopedale.....	Wells and river.....	150,000	250,000	Pumping direct.....	
Nahant.....	Tubular and surface wells.....	30,000	a	a	Marblehead Water Co.'s plant, through a meter.
Newburyport.....	Wells.....	400,000	300,000	Pumping to tank.....	Daily yield of wells, 800,000 gallons.
North Adams.....	Artesian wells (2) and brook.....	1,300,000	10,550,000	Pumping from brook.....	
North Attleboro.....	Well.....	3,453	554,000	Pumping to standpipe.....	Pond has capacity of 125,000,000 gallons.
North Easton.....	Well (near river).....	57	250,000	Pumping to standpipe and direct.....	
Norwood.....	Spring-fed pond.....	30,000	1,400,000	Pumping to reservoir.....	
Orange.....	Springs.....	a	5,000,000	Gravity from reservoir.....	Impounding reservoir, capacity not given.
Peabody.....	Springs and ponds.....	70,000	524,000	Pumping to tank and gravity.....	
Quincy.....	Wells and storage reservoir.....	688,346	180,318,000	Pumping.....	
Revere and Winthrop.....	Driven and collecting wells.....	350,000	a	Pumping to reservoir.....	Furnished by Marblehead Water Co.
Riverside.....	Springs.....	a	1,500,000	Gravity.....	
Salem.....	Spring-fed lake.....	2,111,572	20,000,000	Pumping to reservoir and direct.....	
Sharon.....	Well (near brook).....	50,000	200,000	Pumping to tank.....	60 families supplied from springs; town has several small plants.
Shelburne Falls.....	Mountain springs.....	9,040	a	Gravity.....	
Southbridge.....	Springs and surface water.....	25,000	a	Pumping to reservoir and gravity.....	
Stockbridge.....	Springs, artesian well, and surface water.....	a	6,250,000	Pumping to reservoir.....	Town has several plants—3 supplied from wells—124 families supplied.
Stoughton.....	Well.....	25,000	317,000	Pumping to tank.....	
Sunderland.....	Springs.....	400,000	a	Gravity to reservoir.....	
Swampscott.....	Artesian wells, and surface well.....	400,000	a	Pumping direct.....	30 families supplied.
Taunton.....	Driven wells and surface water.....	751,802	400,000	Pumping to standpipe.....	
Uxbridge.....	Springs.....	3,000	117,000	Pumping to reservoir.....	
Vine and Haven.....	Well.....	a	1,500,000	Gravity from springs, pumping from pond for fires.....	Capacity of springs.
Ware.....	Springs and pond.....	133,350	a	Gravity.....	
Warren.....	Wells and brook.....	a	a	do.....	
West Brookfield.....	Wells and brook.....	a	a	Gravity from reservoir.....	
West Stockbridge.....	Spring.....	a	a		
Whitinsville.....	Springs.....	a	300,000		
[Projected works (with artesian supply) at several other places.]					

MICHIGAN.

Adrian.....	Artesian and surface wells.....	450,000	Pumping direct.....		Pumping machinery, capacity 150,000 gallons.
Allegan.....	Well.....	300,000	Pumping to reservoir.....	9,000,000	
Ann Arbor.....	Springs and surface water.....	500,000	Pumping from collecting reservoir.....	100,000	
Bessemer.....	Driven wells.....	2,000,000	do.....	30,000	
Big Rapids.....	Artesian wells.....	a	Pumping to tank.....	15,000	
Capac.....	Artesian well (sunk into rock).....	a	Pumping to standpipe and direct.....	230,000	
Caro.....	Tubular well (sunk into rock).....	a	Pumping direct.....	a	
Cedar Springs.....	Well and creek.....	a	do.....	a	
Charlotte.....	Wells.....	306,000	do.....	a	
Cheboygan.....	Artesian wells (2).....	530,000	do.....	a	
Clare.....	Well.....	500,000	Pumping from receiving reservoir.....	300,000	
Dowagiac.....	Artesian wells (3).....	a	Pumping to reservoir and direct.....	75,000	
Edmore.....	Tube wells (in surface wells).....	8,000	Pumping direct.....	a	
Evart.....	Springs and wells.....	35,000	do.....	a	
Fenton.....	Artesian wells.....	a	do.....	a	
Flint.....	Wells, creek, and river.....	725,316	do.....	a	
Fremont.....	Flowing artesian wells (4) and springs.....	a	Pumping to tank.....	85,000	
Gaylord.....	Well.....	4,500	Pumping direct.....	a	
Grand Haven.....	Artesian wells and river.....	a	do.....	235,000	
Grand Rapids.....	Driven wells (2 plants).....	550,000	Pumping to standpipe and gravity (from springs).....	a	
Greenville.....	Springs and well.....	a	Pumping direct.....	a	
Hancock.....	Driven wells and river (for fire).....	a	Gravity from reservoir.....	70,000	
Hastings.....	Well.....	300,000	Pumping direct.....	a	
Holland.....	Springs.....	150,000	Pumping from collecting reservoir.....	a	
Ionia.....	Artesian wells (4), springs, and surface water.....	300,000	Pumping direct.....	a	
Ithaca.....	Artesian wells.....	a	Pumping direct.....	a	
Jackson.....	Wells (3) (sunk on iron shoe).....	500,000	do.....	a	
Kalamazoo.....	Artesian well and creek.....	1,700,000	Pumping direct and gravity.....	a	
Lake Linden.....	Tile-lined wells.....	635,000	Pumping to standpipe.....	290,000	
Lansing.....	Artesian wells (3), flowing.....	900,000	Pumping direct (overflow goes to reservoir).....	80,000	
Lapeer.....	Artesian wells (3).....	150,000	Pumping to reservoir.....	a	
Lowell.....	Driven wells (30).....	a	Pumping direct.....	a	
Manistee.....	Combined driven and surface wells.....	700,000	Pumping to standpipe.....	235,000	
Marshall.....	Well.....	a			

Contract let for well.

Projected works reported.

8 wells, 34 feet deep.

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.

MICHIGAN—Continued.

City, town, or village.	Supply (wells, springs, etc.).	Consumption.	Capacity, reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.
Mount Pleasant.....					
Muskegon.....	Combined driven and surface wells.	Gallons, 100,000	Gallons, 170,250	Pumping to tank and direct.....	
Newago.....	Well and river.	1,300,000	a	Pumping direct.....	Pumping machinery capacity 750,000 gallons.
North Muskegon.....	Driven wells (30) and lake.	250,000	a	do.....	Pumping machinery capacity 2,000,000 gallons.
Ovid.....	Wells	100,000	a	do.....	
Owosso.....	Wells or river (or both).	a	a	do.....	
Petoskey.....	Well	100,000	a	Pumping to tank and direct.....	
Pinconning.....	Artesian well	50,000	100,000	Pumping direct.....	
Pontiac.....	Wells and river	45,000	a	do.....	
Reed City.....	Well, spring, and creek	30,000	a	do.....	
St. Johns.....	Artesian wells.	a	150,000	do.....	
St. Louis.....	Artesian wells (2)	a	a	do.....	
Stanton.....	Artesian well	100,000	a	Pumping to reservoir.....	Pumping machinery capacity 1,000,000 gallons.
Sturgis.....	Well	a	a	Pumping direct.....	Pumping machinery capacity 1,750,000 gallons.
Tecumseh.....	do	a	100,000	Pumping to tank.....	
Three Rivers.....	Driven wells (3 1/4 inch, 56 ft. deep)	130,000	105,000	Pumping to standpipe and direct.....	
Vassar.....	Artesian well and river	500,000	254,000	Pumping to tank.....	
Ypsilanti.....	Well	a	a		
[Note.—Works (with artesian supply) projected at other places in State.]					

MINNESOTA.

Alexandria.....	Driven wells	a	a	Pumping direct.....	Pumping machinery capacity 1,000,000 gallons.
Austin.....	Artesian well and river.	60,000	a	do.....	Well for domestic, river for fire purposes.
Cannon Falls.....	Well	a	175,000	Pumping to reservoir.....	
Faribault.....	Wells	100,855	750,000	Pumping to tank.....	
Fort Snelling.....	Spring	40,000	30,000	Pumping to tank and direct.....	
Lanesboro.....	Well (30 feet deep)	a	225,000	Pumping to reservoir.....	Report for 187-'82.

Daily flow in 1882, 1,500,000 gallons.

	Artesian wells (2)	a	250,000	850,000	do. Pumping to reservoir (thence to tank).
Mankato.....	Well			45,000	
New Ulm.....	Well			23,000	
North St. Paul.....	Artesian wells and lake		3,000		Pumping direct and to standpipe.
Pipestone.....	Bored well (300 feet deep)		5,000	91,000	Pumping to standpipe.
Rochester.....	Springs		40,000	235,000	do.
St. Peter.....	Well (near river)	a		151,000	do.
Sandstone.....	Springs (5)	a		2,000,000	Gravity to and from reservoir (probably).
Winona.....	Wells (50 feet deep, near river)		1,184,634	a	Pumping to standpipe.
[NOTE.—Works projected at other points; supply artesian, wells being bored in several places; unfinished at date of manual.]					

MISSISSIPPI

	Artesian wells.	a	300,000	40,000	Gravity
Biloxi.....	Artesian wells (2)	a			Pumping to reservoir
Columbus.....	Springs and surface water		400,000	200,000,000	do.
Meridian.....	Artesian wells	a			
Pass Christian.....	Artesian wells				
[Note.—Works projected at other places; several already have wells.]					
					Capacity of one well 150,000 gallons daily.
					Wells flow from 50 to 75 gallons per minute.

MISSOURI

	Driven wells	a	100,000	93,000	Pumping to standpipe and direct.
Carrollton.....	Artesian well			2,080,000	Pumping to reservoir standpipe and direct.
Clinton.....	Artesian well	a		100,000	Pumping and gravity
Fulton.....	Well		250,000		Pumping and direct
Marshall.....	Springs and surface water		280,000		do.
Mexico.....	Spring		1,000,000	4,000,000	Pumping to reservoir tank and direct.
Springfield.....	Spring			170,000	Pumping to standpipe and direct.
Trenton.....	River and well		200,000		
[NOTE.—Works projected at other places; supply artesian.]					

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.
NEBRASKA (EAST OF 97').

City, town, or village.	Supply (springs, wells, etc.).	Consump- tion.	Capacity of reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.	
Ashland.....	Wells (3 70 feet deep)	Gallons.....	Gallons.....	Pumping to tank.....	New system (Godfrey's), 50 2-inch wells (5 batteries, 10 wells each). Direct- pumping; yield, 2,400,000 gallons. [Eng. News, Nov. 7, 1891.]	
Blair.....	Tube wells (30)	15,000.....	65,000.....	Pumping to reservoir.....		
Frederick.....	Driven wells.....	50,000.....	700,000.....	Pumping to standpipe and direct.....		
		75,000.....	30,000.....			
Lincoln.....	Driven wells (100) and surface well.....	1,500,000.....	140,000.....	Pumping to standpipe.....		
Pawnee City.....	Wells (2 7-inch).....	a.....	80,000.....	Pumping to standpipe and direct.....		
Wahoo.....	Driven wells and river.....	a.....	300,000.....	Pumping direct.....		
Weeping Water.....	Wells.....	a.....	170,000.....	Pumping to reservoir.....		
West Point.....	Driven wells (24)	112,000.....	110,000.....	Pumping to reservoir and direct.....		
Wisner.....	Wells.....	a.....	90,000.....	Pumping to tank.....		
Wymore.....	Well.....	a.....	93,000.....	Pumping to standpipe.....		
[NOTE.—Works projected at other places, some already having wells.]						
NEW HAMPSHIRE.						
Bethlehem.....	Springs.....	180,000.....	250,000.....	Gravity from reservoir.....	Bored logs (for pipes) laid in 1894, still in use.	
Dover.....	Springs and pond.....	a.....	2,000,000.....	Pumping to reservoir.....		
Drewsville.....	Spring.....	a.....	a.....	Gravity.....		
Farmington.....	Springs.....	a.....	a.....	Pumping to reservoir.....		
Gorham.....	do.....	a.....	6,500.....	Gravity.....		
Haver.....	Springs (6)	27,000.....	a.....	do.....		
Lancaster.....	Springs.....	10,000.....	a.....	do.....		
Plymouth.....	do.....	a.....	4,000,000.....	do.....		
Portsmouth.....	Springs (20)	50,000.....	500,000.....	Pumping to reservoir and gravity.....		
West Canaan.....	Spring.....	a.....	a.....	Gravity.....		
The Wells.....	Springs and wells.....	a.....	a.....			
[NOTE.—Works proposed and projected at several other places.]						
Report for 1887-'88.						

NEW JERSEY.

Location	Artesian wells	g	105,000	Pumping to standpipe	City has another plant with supply from other sources.
Asbury Park	do	500,000	198,750	Pumping to standpipe and direct	
Atlantic City	Spring	251,361	112,000	Pumping to standpipe	
Blairstown	Springs, well, and lake	10,000	4,350,000	Pumping to reservoir	
Bridgeton	Springs	600,000	6,000,000	Gravity from collecting reservoir	
Dover	Springs and wells			Pumping direct	
East Orange and Bloomfield	Springs and rivers	75,000	2,145,000	Pumping and gravity	Daily flow of springs, 300,000 gallons.
Flemington	Springs and creek	20,000	2,145,000	Pumping from reservoir to standpipe	
Gloucester City	Well	7,500	46,000	Pumping to standpipe	
Haddonfield	Spring-fed stream	710,000	152,000	Gravity	
Haddonville School	Spring	26,354	847,000	Pumping to standpipe	
Irvington	Springs and brook	20,000	282,000	do	
Long Branch	Stream fed by springs	18,000	70,000	Pumping to tank	
Merchantville	Wells	275,000	19,400,000	Gravity	
Monclair	Spring-fed streams	13,831,256	44,000,000	Pumping to reservoir	
Moorestown	Springs	25,000	28,200	Pumping to standpipe and direct	
Morristown	Tubular wells (70) and river	400,000	315,000	Pumping to tank	
Newark	Springs	15,000	600,000	Gravity	
New Jersey Reform School at Jamesburg	Artesian wells (15)	350,000	20,167,000	Pumping from reservoir to standpipe	
Ocean Grove	Spring	300,000	2,000,000	Pumping to reservoir	
Pennington	Springs	60,000	141,000	Pumping to tank	
Perth Amboy	Springs and surface water	125,000	800,000	Pumping to reservoir and direct	
Phillipsburg	Well	25,000	70,000	Pumping to tank	
Princeton	do	45,000,000	45,000,000	Pumping from reservoir	
Redbank	do	100,000	67,680	Pumping to standpipe	
Riverton and Palmyra	Well and surface water	40,000	183,000	Pumping to reservoir	
Salem	Artesian wells (9)	175,000	75,000	Pumping to tank	
Seabright	Springs	25,000	75,000	Pumping to tank and direct	
Short Hills	Wells				
Summit	Driven wells				
Wenonah	Springs				
[Note.—Works proposed or projected at other places—some having already an artesian supply.]					

Ground water.
In 1887.

Report for 1887-88.

NEW YORK.

Location	Springs	g	15,000	Pumping to standpipe and direct	Estimated wells supply, 15,000,000 gallons daily.
Adams	Driven wells and creek	21,249	184,000,000	Pumping to standpipe	
Albany	Wells	3,000	350,000	Pumping to standpipe	
Albion	Spring		110,000	Gravity	
Andes					

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.

NEW YORK—Continued.

City, town, or village.	Supply (wells, springs, etc.).	Consump- tion.	Capacity, reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.
Attica.....	Springs.....	Gallons. 225,000	Gallons. 12,000,000	Gravity.....	3 reservoirs; 1 has area of 15 acres.
Avoca.....	Springs and creek.....	g.....	1,000,000	do.....	Estimated present supply from An- drews system of wells, 16,000,000 gal- lons daily.
Bainbridge.....	Artesian wells, springs, and res- ervoir.....	g.....	305,000	Pumping to standpipe.....	
Ballston Spa.....	Springs.....	600,000	181,000,000	Pumping to reservoirs (3).....	
Bath.....	Wells and springs.....	100,000			
Brooklyn.....	Open wells and Andrews driven wells.....	40,801,701			
Cambridge.....	Springs.....	40,000	7,000,000	Pumping from collecting reservoir. Gravity.....	No report for 1888-'90.
Canajoharie.....	do.....	g.....	7,000,000	do.....	
Canastota.....	do.....	g.....	2,000,000	do.....	
Canisteo.....	do.....	g.....	233,000	do.....	
Castile.....	do.....	g.....			
Chateaugay.....	Springs.....	300,000	1,500,000	Pumping to reservoir.....	
Chatham.....	Andrews gang wells.....	g.....	300,000	Pumping to standpipe.....	
Oyde.....	Springs.....	g.....	120,000	Gravity.....	
Cobleskill.....	Springs and surface water.....	450,000		Pumping from improved reservoir. Pumping to tank.....	
College Point.....	Springs and creek.....	350,000	3,500,000	Pumping to tank.....	
Cortland.....	Springs.....	300,000	275,000	Gravity.....	
Cortland.....	do.....	g.....	700,000	Pumping to tank.....	
Cuba.....	Artesian wells (2).....	5,000	47,000	Gravity.....	
David's Island.....	Springs.....	g.....	224,000	Pumping to standpipes (2).....	Report for 1887-'88.
Elizabethtown.....	Gang wells (50).....	600,000	224,000	Pumping to standpipes.....	12 wells, 8 feet diameter, 36 feet deep.
Far Rockaway.....	Wells (Stephens system).....	700,000	None.	Pumping direct.....	
Flatbush.....	Bored wells (17) and pond for fires.....	600,000			
Flushing.....	Springs.....	100,000	2,000,000	Gravity.....	
Fonda.....	do.....	g.....	15,000,000	do.....	
Fort Edward.....	do.....	g.....	18,000,000	Pumping to standpipe.....	
Fort Plain.....	do.....	200,000	180,000	Gravity and pumping.....	
Fulton.....	do.....	300,000	165,000	Pumping direct.....	
Fultonville.....	Well (85 feet deep).....	500,000	None.	Pumping and gravity.....	3 reservoirs; but 1 noted.
Garden City.....	Springs.....	g.....		Gravity from reservoirs (2).....	
Geneva.....	do.....	75,000,000		Gravity from reservoirs (4).....	
Glens Falls.....	Springs and creek.....	500,000	40,000,000	Gravity from reservoirs.....	
Gloversville.....	Springs.....	g.....	2,000,000	Gravity.....	
Goshen.....	Springs.....	115,000			
Gowanda.....	do.....	g.....			

Gravesend	Wells (Stephens system)	2,000,000	411,000	Pumping to standpipe and direct	Yield of wells in 1889, 1,000,000 gallons daily.
Greenbush	Well and river	233,466	233,700	Pumping to standpipe	
Greenport	Driven wells (4)	a	200,000	Pumping to reservoir	
Greenwich	Springs	a	a	Gravity from reservoir	
Groton	do	a	a	Gravity	
Hancock	do	a	a	Gravity from reservoir	
Herkimer	Driven wells	a	400,000	Gravity	
Homer	Springs	a	80,000	Pumping to tank	
Honoye Falls	Wells	a	865,542	do	
Horton	do	a	1,000	do	
Irrington	do	a	180,000	do	
Jalap	Artesian well and stream	a	16,000	Pumping to reservoir	
Jamaica	(6-inch) wells (6)	a	322,000	Pumping to standpipe	
Jamestown	Artesian wells	a	600,000	Pumping to tank	
			750,000	Pumping direct	
Johnstown	Springs and streams	a	500,000	Gravity from reservoir	4 8-inch wells yield 2,000,000 gallons daily.
Little Valley	Springs	a	a	Gravity	Capacity of 2 reservoirs not given.
Long Island City	Driven and dug wells	a	a	Pumping direct	
Lyons	Wells	a	117,000	Pumping to standpipe	
Malden	Springs	a	1,600,000	Gravity to and from reservoir	
Middletown	do	a	a	Gravity	
Moravia	Springs and surface water	a	3,000,000	Pumping to reservoir and gravity	Small system.
Mount Morris	Springs (9)	a	100,000	Gravity	
Newark	Springs	a	75,000	do	
			100,000	Pumping to standpipe from collecting reservoir.	
New Berlin	do	a	1,438,000	Gravity to reservoir	Report of 1887-'88.
New Brighton and Port Richmond	Driven wells (40)	a	14,000,000	Pumping to reservoir and direct	
Nunda	Springs	a	60,000	Gravity (and pumping for reserve)	
Nyack	Springs and river	a	2,000,000	Gravity and pumping	Well has 20 3-inch pipes driven in bottom.
Olean	Well	a	650,000	Pumping to reservoir	
Oneida	Springs	a	22,300,000	Gravity from reservoir	
Owego	Springs and creek	a	40,000	Gravity	
Pachogue	Wells (6-inch pipe)	a	285,000	Pumping to standpipe	
Phelps	Springs	a	a	Gravity	
Phoenix	Wells, springs, and river	a	183,000	Pumping to standpipe	
Port Byron	Well	a	500,000	Pumping to reservoir	
Randolph	Springs	a	500,000	Gravity	
Round Lake	Springs	a	170,000	Pumping to tanks	
Sage Harbor	Wells	a	235,000	Pumping to standpipe	
Salamanca	Springs	a	a	Gravity	
Sandy Hill	Springs and surface water	a	300,000	Gravity and pumping	
Saratoga Springs	Springs and brook	a	223,300	Pumping to standpipe	Daily capacity of brook, 750,000 gallons.
Schenectady	Springs and lake	a	100,000	Pumping to tank	
Sea Cliff	Driven wells (7)	a	32,000	Gravity	
Springville	Springs	a	370,000	Pumping from collecting reservoir	
Stapleton and Edgewater	Driven wells	a	a	Pumping direct	

Waterworks (east of "arid region") having their supply from artesian and underground sources—Continued.

NEW YORK—Continued.

City, town, or village.	Supply (wells, springs, etc.).	Consumption.	Capacity of reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.
Syracuse.....	Spring and surface water.	Gallons.	Gallons.	Pumping to reservoir and gravity.	
Tarrytown.....	Well.....	6,000,000	80,000,000	Pumping to reservoir and tank.	
Unadilla.....	Springs.....	a	1,400,000	Pumping and gravity.	Well in swamp.
Warrensburg.....	Spring-fed stream.....	a	2,000,000	do.	
Warsaw.....	Springs.....	a	4,500,000	do.	
Whitehall.....	Spring and surface water.....	800,000	93,000,000	Gravity and pumping.	
White Plains.....	Springs.....	300,000	6,500,000	Pumping to standpipe.	
Whitesboro.....	do.....	20,480	6,275,000	Gravity from reservoir.	
Whitesville.....	do.....	a	35,000	Gravity to reservoir.	

NORTH CAROLINA.

Asheville.....	Springs, river, and surface water.	300,000	1,113,000	Pumping and gravity to reservoir and stand pipe.	
Charlotte.....	Springs.....	300,000	10,190,000	Pumping from imp. reservoir to stand pipe.	Daily capacity of spring, 30,000 gallons.
Concord.....	Spring.....	a	a	Pumping to tank.	
Fayetteville.....	Springs and creek.....	58,000	4,000	Gravity to and from reservoir.	Reservoir being built.
Greensboro.....	Spring.....	180,000	100,000	Gravity to tank.	Well, but works not yet built.
Hendersonville.....	Artesian well.....	a	a	Pumping to reservoir.	Wells (2) have capacity of 40 and 50 gallons per minute.
Newberne.....	Wells (near creek).....	a	450,000	Pumping to tank.	One well yields daily 144,000 gallons.
Salisbury.....	Springs.....	84,400	a	Pumping to reservoir.	
Winston.....	Wells (2).....	130,000	1,000,000	Pumping to reservoir.	

[NOTE.—Works projected at other points—supply, springs, or wells.]

OHIO.

Well	1,500,000	3,500,000	Pumping to reservoir
Well	125,000	10,250,000	Pumping
Flowing wells (2) and springs.	900,000	400,000	Pumping to reservoir
Well, filtered.	200,000	9,000,000	Pumping and gravity
Well, lake and creek	1,100,000		Pumping direct
Well, lake and creek	1,100,000		do
Wells in bottom of settling reservoir and reservoir on creek.	50,000	3,500,000	Pumping to reservoir
Springs	50,000		Pumping direct
Tube wells (30 8-inch).	1,900,000	1,500,000	Gravity from reservoir
Wells and springs.			Pumping direct
Drilled wells (4)		250,000	Pumping direct and to standpipe
Driven wells (6)		300,000	Pumping to reservoir
Springs (mainly)	832,285		Pumping direct
Wells	940,000	2,867,000	Pumping from reservoir to standpipe
Driven wells	35,000		Pumping to standpipe
Wagner wells (steam filter)	800,000		Pumping to tank
Well	700,000	6,705,885	Pumping to reservoir and direct
Well and gallery	200,000		Pumping direct
Springs		135,000	Pumping to tank
Cook wells		500,000	Pumping and gravity
Flowing artesian wells (5) and springs (2).	1,250,000	200,000	Pumping to standpipe and direct
Well (near river)			Pumping direct
Water-bearing gravel stored in water reservoir.		600,000	Pumping direct and to standpipe
Well		15,350,480	Pumping to standpipe
Well (near creek)	500,000		Pumping direct
Springs (2)	27,000		Pumping to tank
Artesian well and surface well.			Pumping to standpipe
Tubular wells (6)	375,000	305,000	Pumping to reservoir and tank
Wells (2) (in gravel)	400,000		Pumping to reservoir
Artesian wells (4) and springs	500,000	2,000,000	do
Wells and river	55,000	400,000	do
Artesian wells	250,000	2,500,000	Pumping to reservoir
Springs		5,000,000	Pumping to standpipe and direct
Artesian wells and springs	300,000		Pumping from reservoir to standpipe
River and wells	200,000	915,000	Pumping to standpipe
Springs	9,000	212,000	Pumping to standpipe
Well	2,000,000	562,600	Pumping from reservoir to standpipe
Springs			do
Well	24,000	300,000	Pumping to standpipe and direct
Springs			

Report for 1887-88.

In 1887.

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.

OHIO—Continued.

City, town, or village.	Supply (wells, springs, etc.).	Consumption.	Capacity of reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.
Urban's.....	Well.....	Gallons.	Gallons.	Pumping direct.....	
Wadsworth.....	Flowing springs (4).....	700,000	a	Gravity.....	
Washington Court House.....	Battery of wells.....	a	294,000	Pumping to standpipe and direct.....	
Waynesburg.....	Springs.....	a	a	Gravity.....	
Wesley.....	Springs and well.....	150,000	12,000,000	Gravity.....	
Xenia.....	Springs.....	300,000	3,251,000	Pumping and pumping.....	
[NOTE.—Works projected at other points: Supply wells or springs.]					
				Pumping direct and to standpipe.....	Small system.

PENNSYLVANIA.

Adrian Mines.....	Artesian well.....	4,000	2,700	Pumping to tanks.....	
Allentown.....	Springs.....	2,400,000	432,000	Pumping to reservoir and standpipe.....	
Bedford.....	do.....	a	2,000,000	Gravity.....	
Bellefonte.....	do.....	500,000	200,000	Pumping to reservoir.....	
Bethlehem.....	Springs.....	650,000	938,000	Pumping direct with tanks.....	
Birdsboro.....	Spring-fed stream.....	30,000	25,000,000	Gravity from reservoir.....	
Boyetown.....	Springs.....	a	25,000	Pumping from storage reservoir to distributing reservoir.....	
Carbondale.....	do.....	150,000	36,000,000	Gravity.....	
Centerville.....	Springs on mountain.....	50,000	a	Gravity from collecting to distributing reservoir.....	
Coatsville.....	Spring-fed stream.....	120,000	3,000,000	Gravity and pumping.....	
Columbia.....	Spring and river.....	400,000	5,000,000	Gravity from imp. reservoirs.....	
Connellsville.....	Springs.....	600,000	30,000,000	Gravity from reservoir (3).....	
Downington.....	do.....	a	8,127,000	Pumping to reservoir and direct.....	
Doylstown.....	do.....	a	8,130,000	Pumping to reservoir.....	
Dubois.....	Springs (6).....	a	2,000,000	Gravity to and from reservoir.....	
East Brady.....	Springs.....	a	372,000	Pumping to tank.....	
Greenburg.....	Artesian well and pond.....	a	150,000	Pumping to reservoir.....	
Greenburg.....	Well.....	a	40,000	Pumping to tank.....	
Hamlet.....	Springs (2).....	a	300,000	Gravity to and from reservoir.....	
Embleton.....	Springs and river.....	a	25,000	Gravity and pumping.....	
Emporium.....	Springs.....	a	1,260,000	Gravity.....	
Ephrata.....	do.....	1,000	60,000	do.....	

Works began 1754. See notes in Manual, p. 251.

From report for 1887-'88.

4 reservoirs, capacity not given.

Franklin	Spring and creek	800,000	17,000,000	Gravity and pumping	In 1887.
Friesland	Artesian well	60,000	300,000	Pumping to reservoir and direct	
Gettysburg	Driven well	60,000	140,000,000	do.	
Greenville	Spring	a	8,000,000	Gravity	
Hanover	Mountain springs	50,000	4,000,000	Gravity from reservoir	
Hazleton	Spring	500,000	25,000,000	Gravity and pumping	
Jenkinson	Artesian wells (2)	a	100,000	Pumping to tank	
Jersey Shore	Spring and surface water	500,000	2,500,000	Pumping to reservoir	
Johnstown	Spring	10,000	a	Gravity	
Kennett Square	Spring and surface water	a	83,000	Pumping to reservoir and stand- pipe	Has two plants, one from mountain streams.
Knox	Well	1,500	a	Pumping to tanks (2)	
Langhorne	Spring	35,000	175,000	Pumping from reservoir to tank	
Landedale	Artesian well	a	58,000	Pumping to tank	
Lehigh	do.	a	600,000	Pumping to reservoir	
Lewistown	Artesian wells (2), springs and creek for emergency	a	500,000	Pumping and gravity	
Litz	Spring	a	9,375	Pumping to tank	
Manay City	Springs and mountain stream	400,000	45,000,000	Gravity from reservoir	
Mechanicsburg	Spring-fed creek	74,000	1,800,000	Pumping to reservoir	Daily capacity of well: flowing, 1,500 gallons; by pumping, 70,000 gallons.
Mechanicsburg	Springs and Artesian well	a	a	Gravity and pumping	
Meersdale	Spring	5,000	63,000	Gravity	
Millersdale	Artesian well	a	1,000,000	do.	
Minersville	Mountain springs	120,000	92,000	Pumping to tanks	City has two tanks—others private.
Mount Carmel	Spring	50,000	a	Gravity	Report for 1887-'88.
Nazareth	do.	15,000	5,000,000	do.	
Newtown	Artesian wells (2)	20,000	194,000	Gravity and pumping to reservoir	
North Charlestown	Artesian well	a	35,000	Pumping direct and to tank	
North Wales	Springs	50,000	a	Gravity	
Oil City	Springs and wells (2)	a	54,000	Pumping through mains to tank	
Oxford	Springs and river	a	2,500,000	Gravity and pumping to reservoir	Do.
Pen Argyl	Bored wells (2)	a	500,000	Pumping to reservoir	
Petrolia	Spring	40,000	1,000,000	Gravity	
Philadelphia	Artesian well	1,600	48,000	Pumping to tank and direct	Yield of well in 1883 300,000 gallons daily.
Plymouth	Well and spring (Chestnut Hill Works)	a	a	Pumping	Daily capacity 750,000 gallons. City has several other works.
Reading	Springs and surface water, Ar- tesian well and river	650,000	9,300,000	Gravity from improved reservoir pumping to reservoir	Yield of well in 1886, flow 30,000 gallon daily; by pumping 150,000 gallons daily.
Reynoldsville	Springs (3) and creeks (2)	3,500,000	184,250,000		Minimum daily flow of springs 350,000 gallons.
Ridley Park	Spring	1,600	72,000	Pumping to tanks	
Royersford	Artesian wells and lake	a	75,000	Pumping to tanks	
St. Petersburg	Artesian wells	a	184,000	Pumping to standpipe	
Schuylkill Haven	Spring	30,000	117,000	Gravity	
	do.	a	8,000,000	Gravity and pumping	

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.

PENNSYLVANIA—Continued.

City, town, or village.	Supply (wells, springs, etc.).	Consumption. Gallons.	Capacity of reservoir, tank, or standpipe. Gallons.	Mode of service (pumping or gravity).	Remarks.
Gewickly.....	Springs and wells.....	150,000	4,000,000	Gravity and pumping.....	
Shickshinny.....	Springs-fed creek.....	300,000	a	Gravity.....	
Shippensburg.....	Mountain springs.....	100,000	700,000	do.....	
Shillington.....	do.....	324,000	a	do.....	
South Easton.....	Springs.....	a	375,000	do.....	
Stroudsburg.....	Tunnel in mountain.....	40,000	750,000	do.....	
Sunbury.....	Springs and surface water.....	6,000	a	Pumping from imp. reservoir to distributing reservoir.	Daily yield, 70,000 gallons
Tarentum.....	Springs.....	30,000	500,000	Pumping to reservoir.....	
Tidoute.....	Springs-fed streams.....	a	500,000	Gravity.....	
Tioga.....	do.....	200,000	15,000,000	Gravity and pumping.....	
Titusville.....	Wells (3).....	1,000,000	a	Pumping direct.....	
Tremont.....	Springs and mountain stream.....	a	7,000,000	do.....	
Tunkhannock.....	Springs.....	200,000	a	Pumping to reservoir.....	
Ulysses.....	Springs and river.....	a	600,000	Gravity and pumping.....	
Uniontown.....	Springs.....	a	24,000,000	Pumping to tanks.....	
Walston.....	Artesian wells (3) and river.....	2,000	12,000	Gravity.....	
Waynesboro.....	Mountain springs.....	a	200,000	Gravity to and from reservoir.....	
Weatherly.....	Springs and creek.....	a	700,000	Pumping to reservoir.....	
West Chester.....	Springs-fed creek.....	400,000	2,500,000	Pumping.....	
Xork.....	Springs and surface water.....	600,000	11,000,000	Gravity.....	
Xustin.....	Springs, wells, and brooks.....	a	a	Pumping.....	
Berwick.....	Springs (near river).....	a	a	Pumping to reservoir.....	
Mauch Chunk and East Mauch Chunk.....	Springs.....	a	a	Gravity.....	
Millford.....	Springs.....	a	a	do.....	
Minooka.....	Springs.....	a	a	do.....	
Shenandoah.....	Mountain springs.....	a	a	do.....	
Susquehanna.....	Springs.....	a	a	do.....	

Report for 1887-'88.

RHODE ISLAND.

Drownville	Well and pond	6,000	52,000	Pumping to tank
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SOUTH CAROLINA.

Charleston	Artesian wells (3)	1,000,000	13,170,000	Pumping to standpipe and gravity to reservoir.	To standpipe for domestic use. Water passes to reservoir for fire.
Columbia	Springs and rivers	600,000	6,500,000	Pumping to reservoir	
Orangeburgh	Artesian wells (2)	35,000	35,000	Pumping to standpipe	
[Proposed works.—Bamberg: Has an artesian well; daily yield 275,000 gallons. Barnwell: Has artesian well with daily yield in 1890 of 275,000 gallons; works authorized. Batesburg: Artesian wells proposed.]					

TENNESSEE.

Athens	Springs	a	50,000	Pumping to standpipe
Bristol	do	200,000	100,000	Pumping to tank
Chattanooga	do	500,000	500,000	Pumping direct
Manchester	do	8,000,000	8,000,000	do
Memphis	Artesian wells (38)	a	37,000	Pumping direct and to standpipe
Monticello	Springs	a	30,000	Pumping to tank
Murfreesboro	Springs	a	a	Pumping to tank
South Pittsburg	Springs	a	a	Pumping and gravity
[Proposed works.—Covington: Has spring with yield of 75 gallons per minute; contract for works made. Fayetteville: Franchise granted; supply from springs or river. Newbern: Has 6-inch wells; surveys made. Sherman Heights: Has large spring. Tullahoma: Has springs. Union City: Franchise and contract granted; supply wells.]				

VERMONT.

Bellows Falls	Lake (fed by springs)	a	a	Gravity	Has two systems of work. Supply from one pond.
Bennington	Springs	a	a	do	
Brandon	Pond (fed by springs)	a	a	do	
Brattleboro	Springs	50,000	7,500,000	do	
Fairhaven	Pond (fed by springs)	45,000	a	do	
Hyde Park	Springs	7,000	a	Gravity and pumping	
Island Pond	do	30,000	a	Gravity	
Montpelier	do	a	a	do	

Waterworks (east of "arid region") having their supply from artesian and underflow sources—Continued.

VERMONT—Continued.

City, town, or village.	Supply (wells, springs, etc.).	Consump- tion.	Capacity of reservoir, tank, or standpipe.	Mode of service (pumping or gravity).	Remarks.
Morrisville	do	Gallons.	Gallons.	Gravity	City has another system. Supply, a river.
Northfield	do	a	a	do	
Richford	do	a	1,000,000	do	
St. Johnsbury	do	a	a	do	
Springfield	Springs (4)	4,800	a	do	
Waterbury	Springs	a	1,000,000	do	
West Randolph	Springs and brooks	a	5,000,000	do	
Winooski	Springs	100,000	a	do	

VIRGINIA.

Charlottesville	Springs and surface water	10,000	122,000,000	Gravity from reservoir	For fires all streets have cisterns; ca- pacity, 8,000 to 10,000 gallons.
Chatham	Springs (4)	1,000	67,500	Gravity	
Crooke	Drives wells (11-inch pipes)	125,000	40,000	Pumping to tank	
Fortress Monroe	Two systems, one from springs; no data.	20,000	72,000	do	
Fredericksburg	Springs	a	800,000	Gravity	
Gordonsville	Gang wells, (National Soldiers' Home).	200,000	a	Pumping direct	
Hampton	Artesian wells	a	1,000,000	Pumping to reservoir	Report for 1897-'98. No report for 1899-'00.
Harrisonburg	Springs	a	a	Gravity	
Leesburg	Springs	a	2,508,000	do	
Lexington	Mountain spring	90,000	a	Gravity to standpipe	
Liberty	Springs (on mountain)	150,000	a	Pumping to reservoir and direct	
Marion	Springs (in limestone)	1,560,000	2,500,000	Pumping to and from reservoir	
Roanoke	10 springs (in limestone)	40,000	2,500,000	Gravity	
Salem	Spring	800,000	35,000	do	
Staunton	Lance spring	a	1,000,000	Pumping to and from reservoir	
Tazewell	[Works projected—Pulaski City: Has two artesian wells.]	a	a		
Winchester		a	a		
Wytheville		a	a		

WEST VIRGINIA.

Bluefield	Springs	80,000 300,000	50,000	Gravity	Proposed increase of reservoir capacity to 1,500,000 gallons.
Martinsburg	do			Pumping direct	
				Pumping to standpipe	
				Gravity	
WISCONSIN.					
Appleton	Artesian wells (3) and river	600,000	2,500,000	Pumping direct	
Baraboo	Springs	60,730	275,000	Pumping to standpipe	
Bayfield	do	a	350,000	Gravity	
Beaver Dam	Well 30 feet diameter, 40 feet	40,000	100,000	Pumping to standpipe	
Beloit	deep	500,000	a	Pumping to tank and direct	
Black River Falls	Driven wells, 48 2-inch points	50,000	100,000	Pumping to standpipe	
Buckingham	Well	a	70,000	do	
Darlington	Artesian wells	12,000	115,000	Pumping to reservoir	
De Pere	Artesian well (flowing)	a	100,000	Gravity	
Eau Claire	Springs	1,000,000	30,000,000	Pumping to standpipe	
Fond du Lac	Artesian wells (4)	1,000,000	3,000,000	Pumping direct and storage reser- voir for fire	
				do	
Green Bay and Fort How- ard	Artesian wells (2)	300,000	900,000		Flow of wells, 300 gallons per minute.
Hudson	Artesian well	a	300,000	Pumping to underground reservoir	
Janesville	do	95,000	300,000	Pumping to standpipe and direct	
Kenosha	Artesian wells (4)	400,000	1,000,000	Gravity	
Madison	Artesian wells (8)	704,000	a	Pumping to standpipe with stor- age reservoir	
Menominee	Springs and river	75,853	88,000	Pumping to standpipe and direct	
Oshkosh	Artesian wells and lake	1,300,000	a	Pumping direct	
Prairie du Chien	Artesian well	a	a	Gravity	
Racine b					
Richland Center	Artesian well	a	600,000	Pumping to reservoir	
Wauchesa	Artesian well (1) and surface wells (2)	100,000	330,000	Pumping to standpipe and direct	
Wausau	Well	a		Pumping direct	
West De Pere	Artesian well	438,249		Gravity	
Whitewater	do	a			No report for 1890-'90. Daily yield in 1889 of 500,000 gallons.

Prior to 1887 had 2 artesian wells each
yielding daily 350,000 gallons. New
works in 1887. Supply Lake Michi-
gan. Not known if well supply is now
used.